Route 1 Station 46 and Pleasant Cove Bridge over Back River Creek
Woolwich, ME
Hydrology & Hydraulics Report
FINAL

July 2021

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The following is the hydrology and hydraulics (H&H) report for the Station 46 Bridge (#3039) over Maine Central Railroad and Back River Creek and the proposed Pleasant Cove Bridge (#6667) over Back River Creek on U.S. Route 1 in Woolwich, ME.

1.0 INTRODUCTION

Back River Marsh is an approximately 140-acre wetland system located upstream of Pleasant Cove and the Sasanoa River in Woolwich, Maine. Back River Marsh is a complex tidal environment which is affected both by riverine and groundwater freshwater flows from the relatively small Back River Creek Basin, as well as tidal and riverine flow inputs from the Gulf of Maine, and/or the Kennebec River depending on conditions in those systems. Tidal flow to the marsh system is currently impaired due to a series of culverts underneath US-1 and George Wright Road which bisect the marsh at its downstream edge (Figure 1). The system is additionally crossed by the Rockland Branch Railroad in the middle of the marsh, and Middle Road (ME-127) at the most upstream end of the marsh, where additional culverts further restrict flow. For the purposes of this report, the lower marsh basin is between US-1 and the railroad crossing, and the upper marsh basin is between the railroad crossing and Middle Road. This Hydraulics and Hydrology (H&H) study was conducted for evaluation of the proposed bridge structures, but also to evaluate the potential to restore salt marsh, provide habitat and infrastructure resiliency in the face of rising sea levels.

Figure 1 **Site map of Back River Creek in Woolwich, ME**

Tidal flow through US-1 and George Wright Road is currently facilitated through a series of four culverts (3 through US-1 and 1 through George Wright Road). The George Wright Road culvert (Figure 2) dates to 1934 and is known as Dyke Bridge. An inspection of the culvert in 2017 found that the culvert was in "poor condition". Three (3) additional culverts of various sizes facilitate flow under US-1. US-1 has been observed to flood under present existing day conditions[1]. The resilience of the roadway under future sea level rise conditions is of concern and, therefore,

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[1] The existing US-1 roadway has been subject to flooding in recent events (March 2, 2018, October 28, and December 14, 2019) and a recent analysis of flood frequency indicates the roadway is subject to flooding in a 2-year return period event (50% chance of occurrence in any given year (Woods Hole Group, 2021).

Maine Department of Transportation (MaineDOT) is in the design process for bridge replacements with the goal of improving the US-1 crossing. The Station 46 Bridge which encompasses the western portion of US-1 that crosses over the Back River Marsh was built in 1933 and rebuilt in 1981. A bridge inspection in 2017 found the bridge substructure to be in poor condition. As such, possible alternatives to restore the Back River marsh and increase resiliency along US-1 need to tie into plans for the future Station 46 Bridge.

Figure 2 **Culvert underneath George Wright Road. Photo taken downstream of Back River Marsh.**

2.0 FIELD ASSESSMENT

An initial phase of the study included a field assessment to gain a better understanding of existing conditions within the marsh system. A limited topographic/bathymetric elevation survey was performed to get detailed channel and marsh surface elevations, as well as information on the existing hydraulic structures to use in the hydrodynamic modeling. Additionally, six tide gauges were deployed to understand the existing tidal dynamics throughout the system. The methods and results of each of these two field tasks are summarized below.

2.1 ELEVATION SURVEY

A small topographic/bathymetric survey of Back River Marsh was conducted on August 8th, 2019, to acquire detailed channel and marsh surface elevations to compare with available LiDAR digital elevation models (DEMs) for use in the hydrodynamic modeling. Culverts were also surveyed and measured for input into the model. The elevation survey was conducted using a Trimble R-8 Real-Time Kinematic (RTK) global positioning system (GPS), interfaced with the KeyNet Virtual Reference Station (VRS) network, allowing for centimeter-level vertical and horizontal accuracy. Figure 3 shows the extent of Woods Hole Group's survey.

Several additional surveys were conducted by project partners and incorporated into the set of the topography and bathymetric information that defined the model grid. Surveys of US-1, George Wright Road, the Rockland Branch Railroad stream crossing, and ME – 127 were conducted by ME-DOT. Additionally, ME-DOT conducted a bathymetric survey of the Back River Creek channel south of the Rockland Branch Railroad crossing. The Kennebec Estuary Land Trust (KELT) collected additional marsh platform surveys which were also incorporated into the overall topographic datasets and used to correct the available LiDAR digital elevation models.

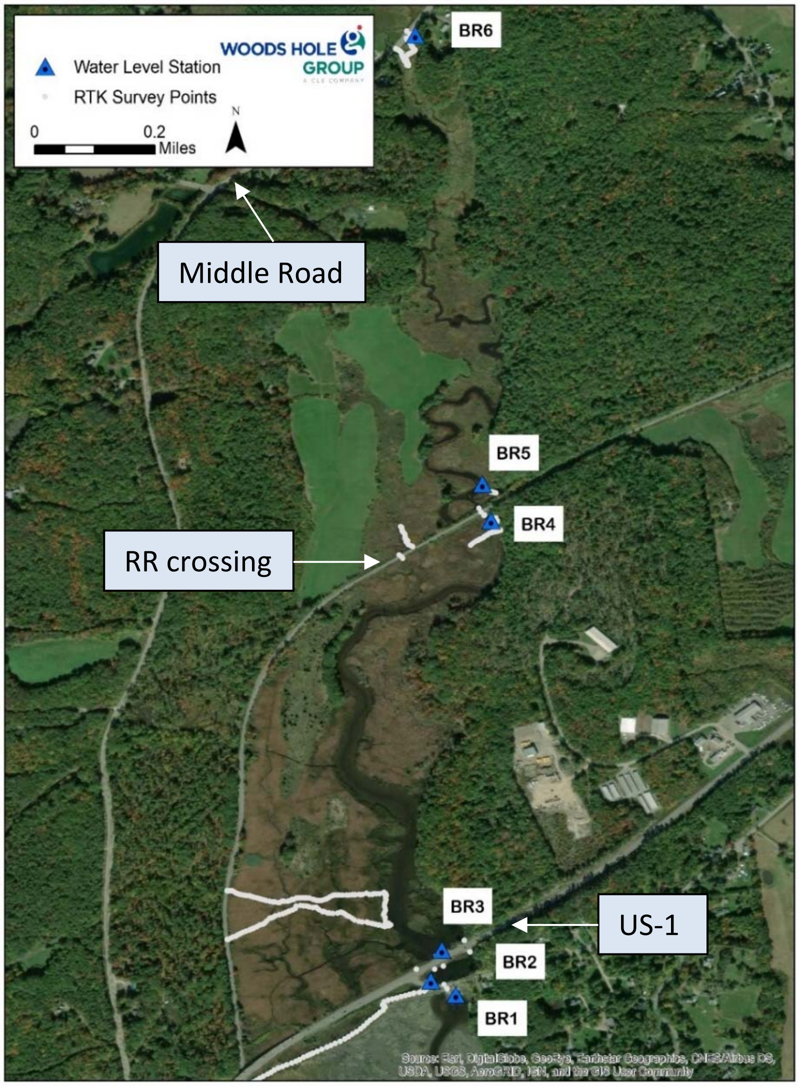


Figure 3 **Water level stations and survey points from Fall 2019 survey of Back River Marsh.**

2.2 TIDE GAUGES

Water level stations were installed at six key locations in the Back River system to understand existing system hydraulics as well as to calibrate and validate the subsequent modeling effort. The six water level stations were located downstream (BR1) and upstream (BR2) of George Wright Road, upstream of Route 1 (BR3), downstream (BR4) and upstream (BR5) of the railroad crossing, and downstream of Route 127 (BR6) (shown in Figure 3 and listed in Table 1). Stations were deployed on August 6th and recovered September 9th and 10th, 2019, giving a 34-day measurement period.

All six water level stations utilized the In-Situ Aqua Troll 200 to measure and log pressure, conductivity, and temperature at a six-minute interval. Six-minute water level measurements are the standard used by NOAA, consequently this sampling interval was used to allow for an easy comparison to nearby NOAA tide stations.

Table 1 Water level station Locations and elevations

Water Level Station	Latitude	Longitude	Elevation (Feet, NAVD88)
BR1	43.92481	-69.79310	-4.85
BR2	43.92552	-69.79284	-1.50
BR3	43.92449	-69.79251	-1.42
BR4	43.93549	-69.79165	-0.60
BR5	43.93633	-69.79186	-0.03
BR6	43.94672	-69.79348	1.56

During deployment and recovery, the sensor elevation for each water level station was surveyed using a Trimble® R8 and/or R10 GPS receiver, a RTK GPS providing centimeter-level geodetic positioning. The system operates by receiving position corrections in real time from the KeyStone KeyNet VRS network over the cellular data network. The RTK GPS measurements were used to determine an elevation relative to North American Vertical Datum 1988 (NAVD88) for each instrument. Deployment and recovery elevations were compared to assess instrument shift during deployment.

Precipitation data was downloaded from the nearby Wiscasset Airport NEWA weather station. Data were recorded hourly and were available for the duration of the measurement period. Site-specific atmospheric pressure data for the monitoring period were provided by the U.S. Fish and Wildlife Service. This site-specific atmospheric pressure was removed from the Aqua Troll 200 absolute pressure record to produce the true pressure caused by the water column. Sensor elevation data measured by the RTK were then used to render the pressure data to water surface elevation relative to NAVD88.

A full record of water level, conductivity and temperature were recorded over the 34-day deployment, capturing both spring and neap tide cycles (Figure 4). Stations BR1 through BR5 were tidally influenced, with a reduction in tide range moving upstream due to the existing hydraulic structures and other natural features. The tide range is reduced from 9.1 feet at BR1 to 4.7 and 4.1 feet at BR2 and BR3 respectively, and 2.6 and then 2.5 feet at BR4 and BR5. The water level at BR6 was perched, appearing to be primarily controlled by precipitation events (Figure 5 and Figure 6).

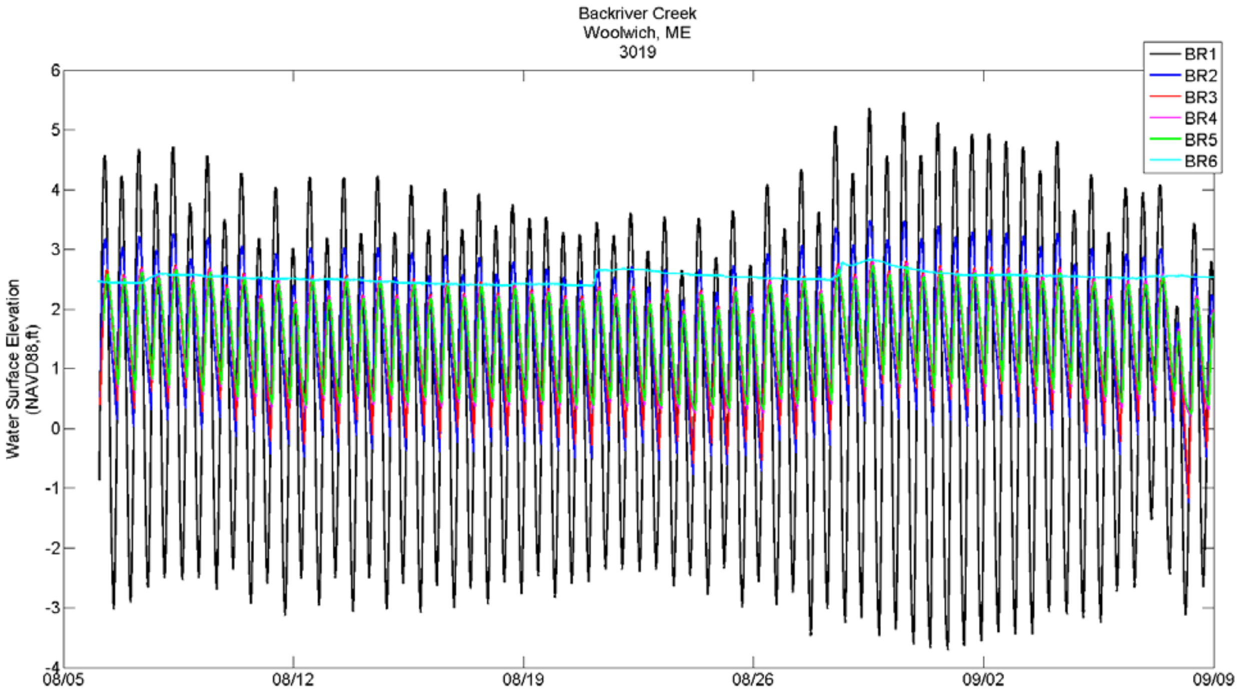


Figure 4 **Time series of post-processed water surface elevation collected in Back River Creek August to September 2019 in feet relative to NAVD88.**

Daily precipitation is presented with the measured tides in Figure 6. Four days had 0.5 inches or more of precipitation, of which the highest rain totals occurred on August 21st and 29th with precipitation of 1.2 inches and 1.0 inches, respectively. Both events appear to raise water levels, with a noticeable increase at BR6.

Salinity naturally followed the tidal restrictions, with BR1 exhibiting the largest range from 3 to 23 psu (Figure 7). The stations upstream and downstream of the railroad crossing were consistently brackish, ranging from 4 to 7 psu. Freshening events are particularly noticeable at BR1, with drops in salinity corresponding with higher precipitation amounts on August 28th and 29th. Figure 8 shows the time-series of temperature recorded at each station during the deployment.

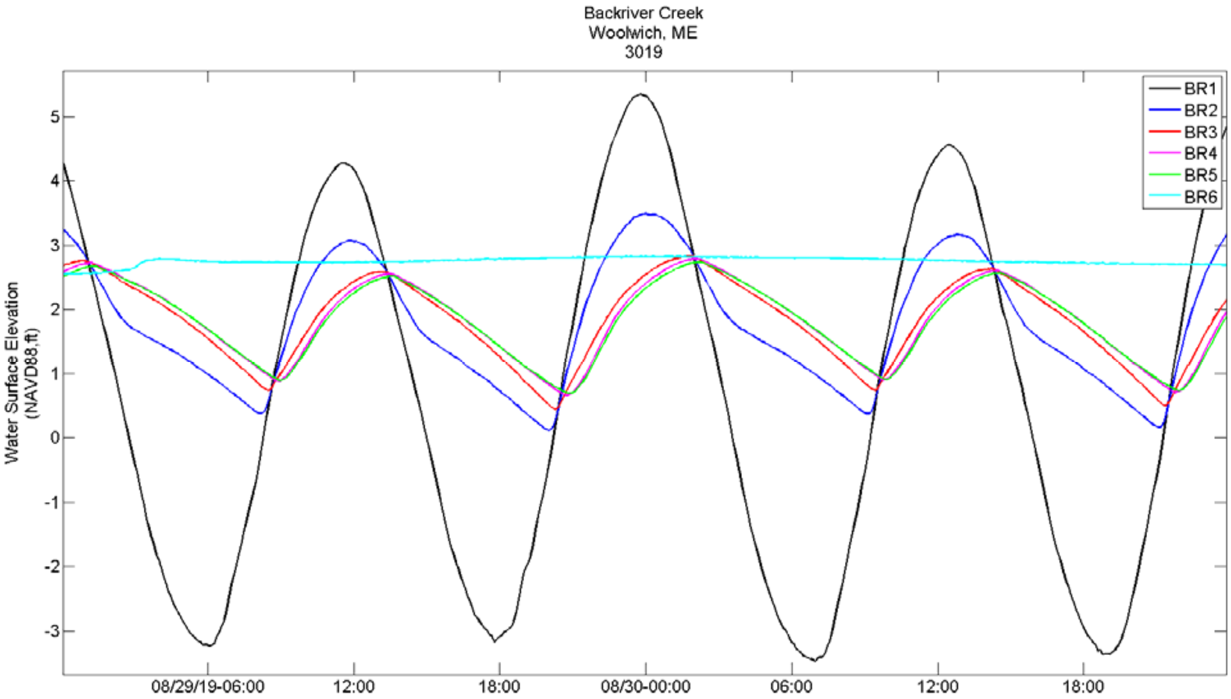


Figure 5 Two-day view of water surface elevation time series from August 29, 2019, to August 31, 2019

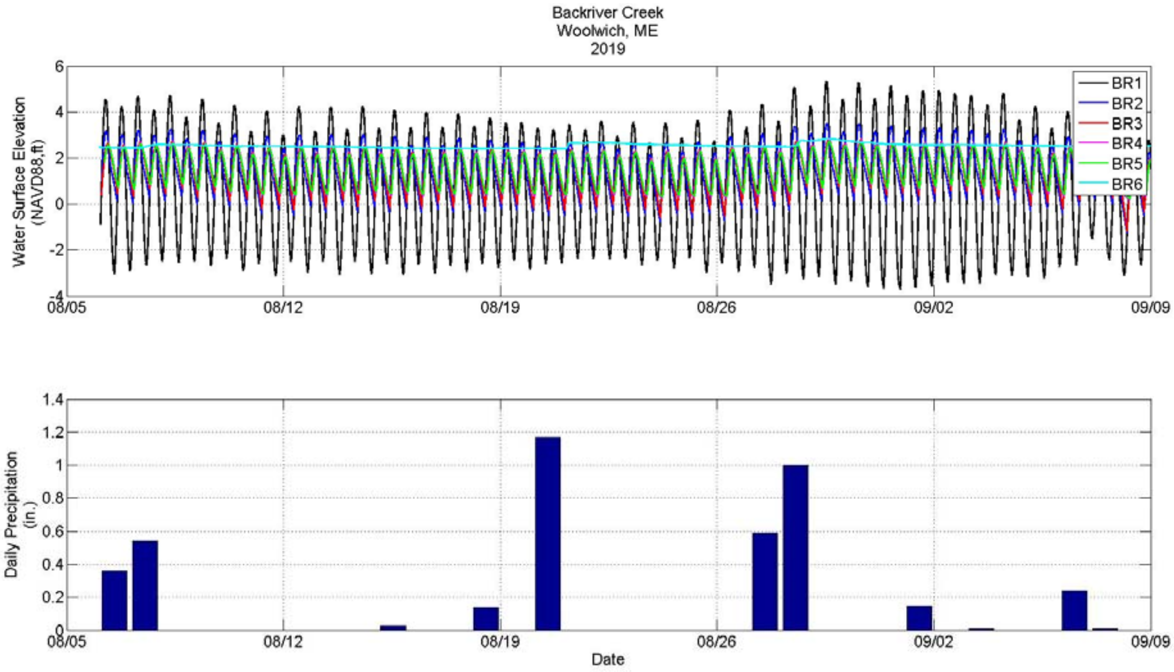


Figure 6 Water surface elevation (feet, navd88, top) and daily precipitation (inches, bottom) measured at the Wiscasset Airport during deployment

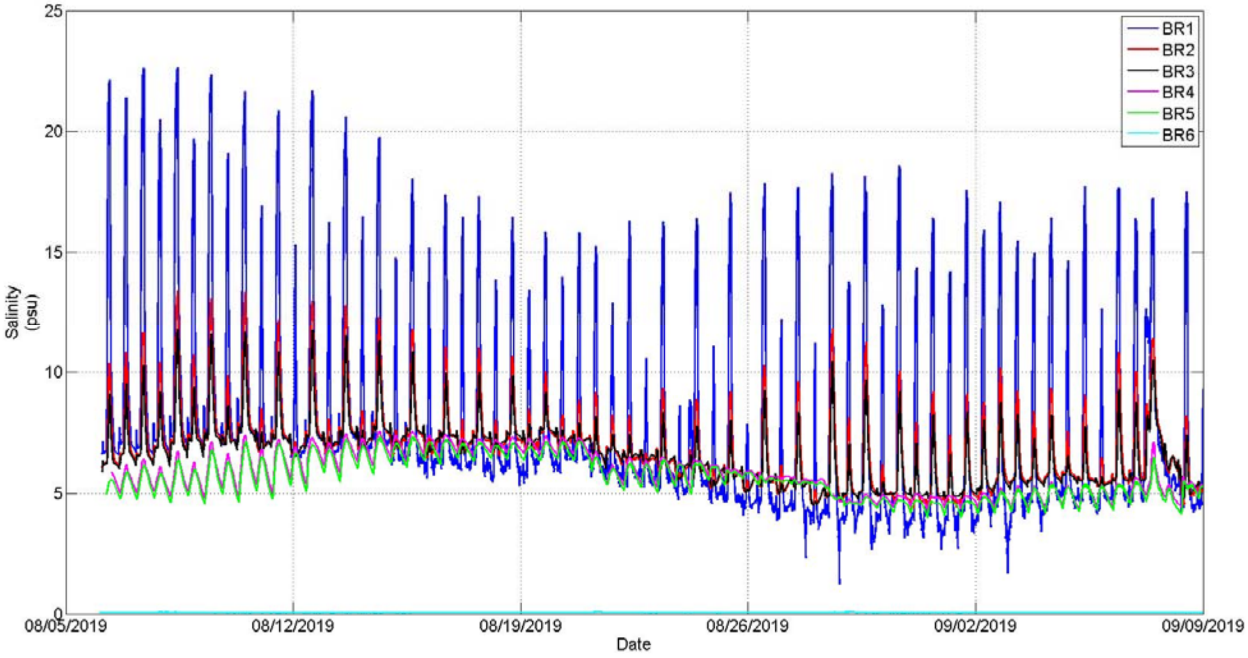


Figure 7 Time series of salinity measured at each station during deployment

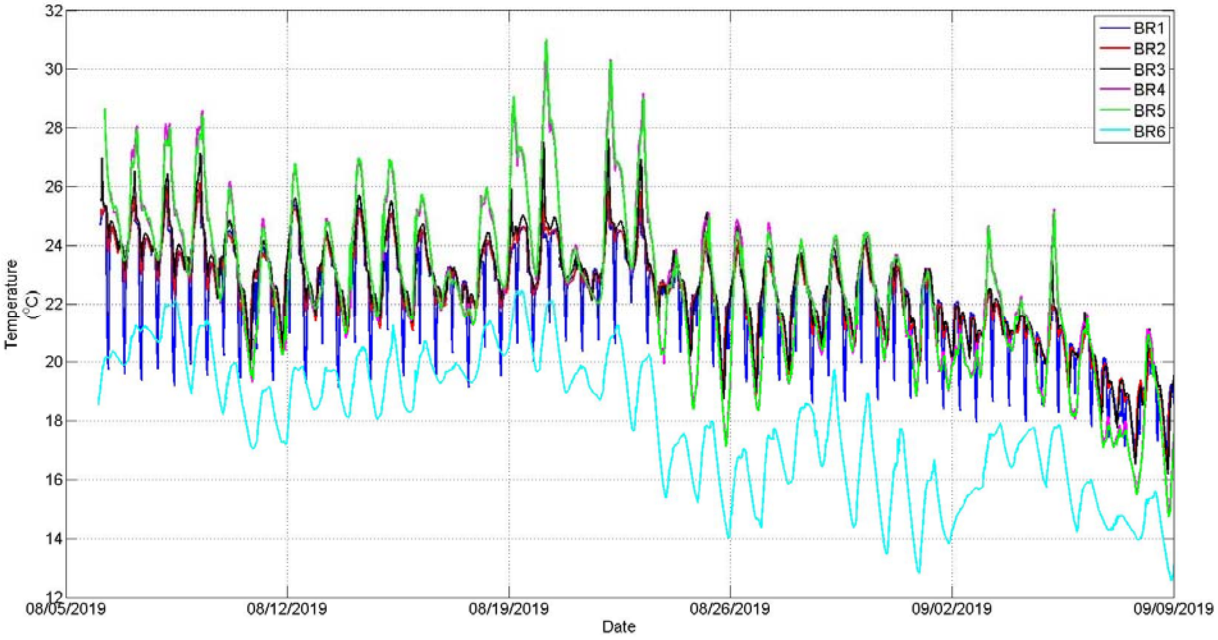


Figure 8 Time series of temperature measured at each station during deployment

3.0 MODEL DEVELOPMENT AND CALIBRATION

To investigate existing conditions and tidal crossing alternatives, a 2-D hydrodynamic model was developed for the Back River Marsh system. The 2-D model provides additional insight into current velocities and water surface elevations throughout the entire marsh system. Sections 3.1 and 3.2 describe the development of the hydrodynamic model; details are provided for the model configuration, boundary conditions, and calibration steps performed.

3.1 MODEL DESCRIPTION

The Sedimentation and Riverine Hydraulics (SRH-2D) model was selected for the Back River Creek system. SRH-2D was developed by the US Department of Interior's Bureau of Reclamation and is capable of simulating flows from multiple streams in both main channels and overland flows (Lai, 2008). SRH-2D solves for the depth-averaged St. Venant equations over a flexible computational mesh comprised of both quadrilateral and triangular elements that define the primary waterways and surrounding topography. The SRH-2D model is capable of computing subcritical, supercritical, and transcritical flows and incorporates a wetting and drying algorithm for computational elements in the overland portions of the model. SRH allows for the specification of a wide variety of internal (within the computational mesh) and external (adjacent to the extents of the mesh) boundary conditions to effectively model complex estuarine dynamics under a wide array of tidal water levels and inflow rates.

3.2 MODEL CONFIGURATION

This section presents the site-specific data utilized to configure the SRH-2D model. The development of the Back River Marsh model required configuration so that the underlying bathymetry/topography and hydrodynamics of the marsh system and the various hydraulic controls were adequately represented in the model. The required data included topographic data to define the model geometry, culvert geometry data to define the hydraulic structures, and tide and storm data to force the model.

3.2.1 Mesh Generation

Mesh generation is one of the first steps in developing a 2-D model. The mesh represents a generalization of topography and bathymetry of the study area with varying resolution. The Back River Marsh mesh was created by visual inspection of aerial imagery and elevations of the area. The mesh extents were chosen to encompass all areas within the floodplain in the vicinity of the marsh. SRH-2D allows for the use of an unstructured mesh made up of quadrilateral and triangular cells. An unstructured mesh allows for variable cell sizes, allowing for more detailed calculations in areas of importance, and varying cell shapes, allowing for more accurate representation of a system's geometry, which is especially important in marshes with complicated channels.

For the Back River marsh system, a minimum 6-ft horizontal resolution was utilized to define the most complex areas of the mesh (including channels and areas around culverts), while varying degrees of coarser resolution was used in other areas. Ensuring adequate cell coverage within the channels and around structures helped to increase model stability and improve model accuracy. The Back River Marsh model mesh is made up of approximately 33,000 computational cells. Figure 9 shows the model mesh generated for Back River Marsh.

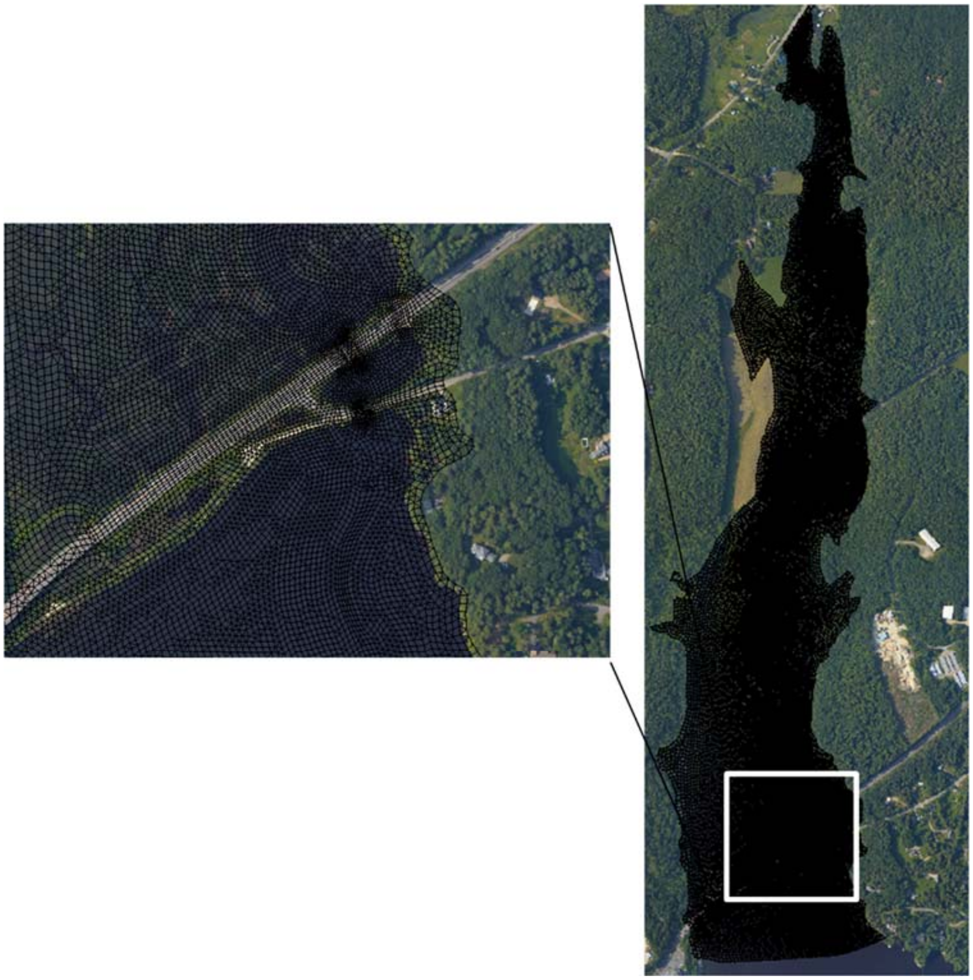


Figure 9 **SRH-2D unstructured model mesh for Back River Marsh**

3.2.2 Model Topography and Bathymetry

The topography and bathymetry specified at each cell in the Back River Model were defined using a combination of the 2011 United States Geological Survey (USGS) Topographic LiDAR: LiDAR for the Northeast Digital Elevation Model (DEM) (OCM Partners, 2021), surveys of the roads within the project area (provided by MaineDOT), and a hydrographic survey of the lower basin channels conducted by MaineDOT in the summer of 2019.

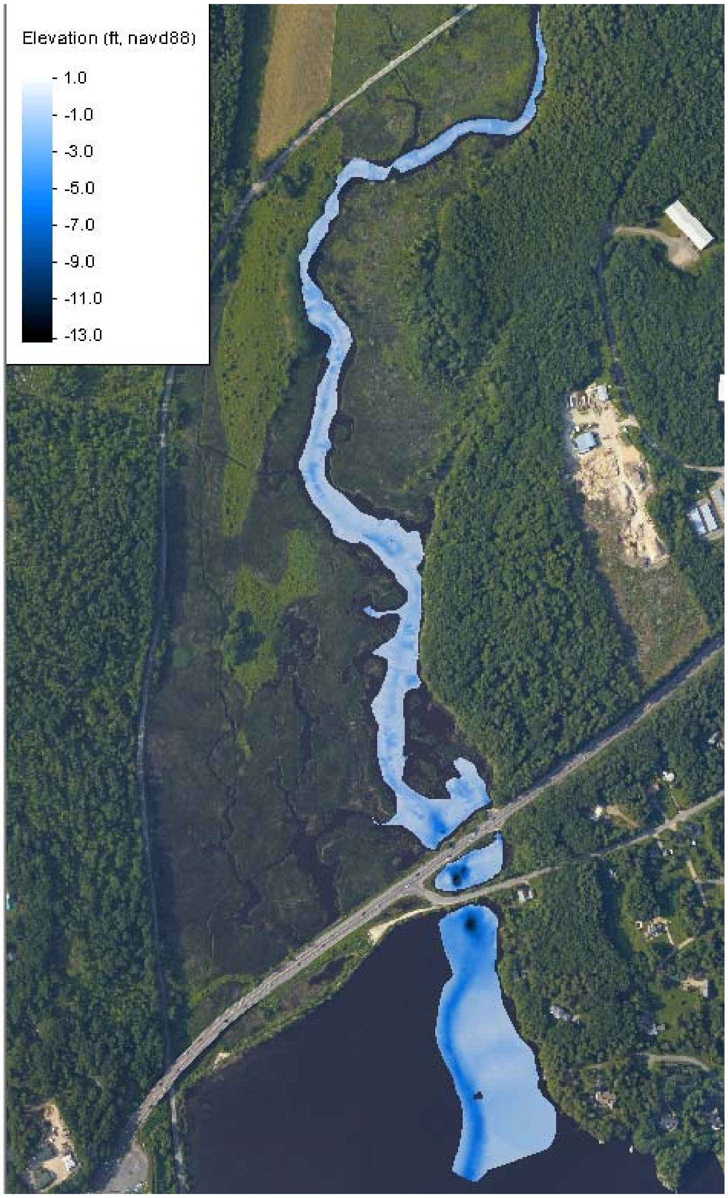


Figure 10 **Interpolated bathymetric data collected by ME-DOT in the lower Back River Creek basin in the summer of 2019**

Comparison of the 2011 USGS LiDAR DEM with the marsh RTK surveys performed by Woods Hole Group and KELT showed that the LiDAR data was biased high in areas of high/dense vegetation. This bias was likely caused by limited bare earth returns in the LiDAR survey in those areas. The bias was shown to vary both spatially and with vegetation type. As such, spatially varying correction factors were applied to the LiDAR DEM based on vegetation as mapped by KELT and Woods Hole Group prior to incorporating in the model. Figure 11 shows areas where vegetation-based corrections were applied. A uniform -1.1 ft correction was applied in the areas shown as "Mixed Shrub" in Figure 11 based on the average bias seen between the survey data and the LiDAR dataset. More variation was observed in the Typha vegetated areas and, as such, spatially varying correction factors were applied in these areas based on mapping of vegetation and observations by KELT. The areas where these corrections were applied are shown in Figure 12. Figure 12 also shows the statistics of the variation between the surveys conducted by KELT and Woods Hole Group and the LiDAR dataset in an inlaid table. The correction factor for each of these areas was the mean of the bias observed in all the survey points in each respective Typha area.

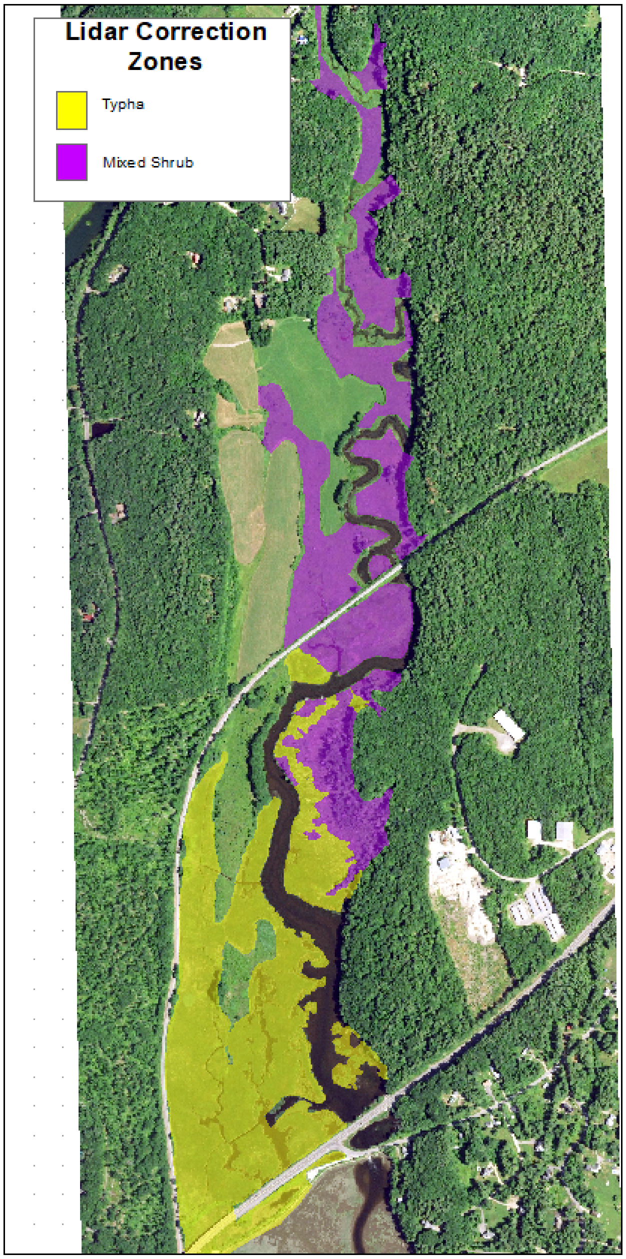
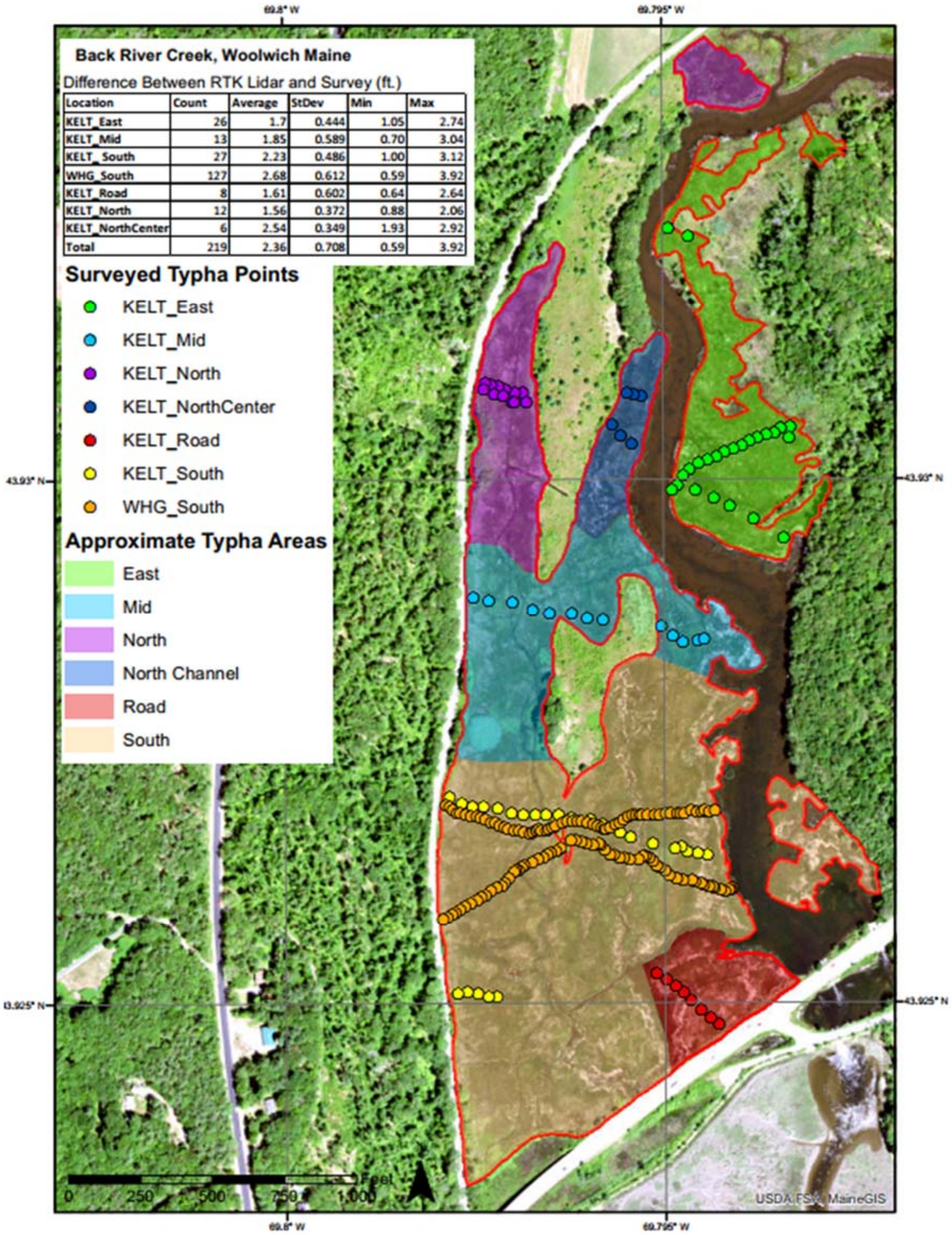


Figure 11 LiDAR correction areas mapped by vegetation type



Back River Creek, Woolwich Maine

Difference Between RTK Lidar and Survey (ft.)

Location	Count	Average	StDev	Min	Max
KELT_East	26	1.7	0.444	1.05	2.74
KELT_Mid	13	1.85	0.589	0.70	3.04
KELT_ South	27	2.23	0.486	1.00	3.12
WHG_South	127	2.68	0.612	0.59	3.92
KELT_Road	8	1.61	0.602	0.64	2.64
KELT_North	12	1.56	0.372	0.88	2.06
KELT_NorthCenter	6	2.54	0.349	1.93	2.92
Total	219	2.36	0.708	0.59	3.92

Figure 12 LiDAR correction areas for Typha type vegetation as mapped by KELT. In-laid table shows statistics of bias between LiDAR and survey data in the different areas.

The topographic and bathymetric datasets were utilized to refine the model mesh and the best available datasets for each area within model domain (combining all the topographic and bathymetric surveys, LiDAR datasets, and RTK survey points) were interpolated to the model mesh.

No bathymetric data was collected or available in the Upper Back River Creek (upstream of the railroad crossing) portion of the model domain and, as such, an artificial channel was developed and inserted into the model grid in this area. The artificial channel was developed based on realistic stream slopes and calibration of the model using the water level gauge at location BR6 (Figure 3). Multiple channel profiles were tested, and a profile was selected based on the best calibration of the model in comparison to station BR6. Figure 13 shows the final topography and bathymetry of the model mesh developed using all of these datasets.

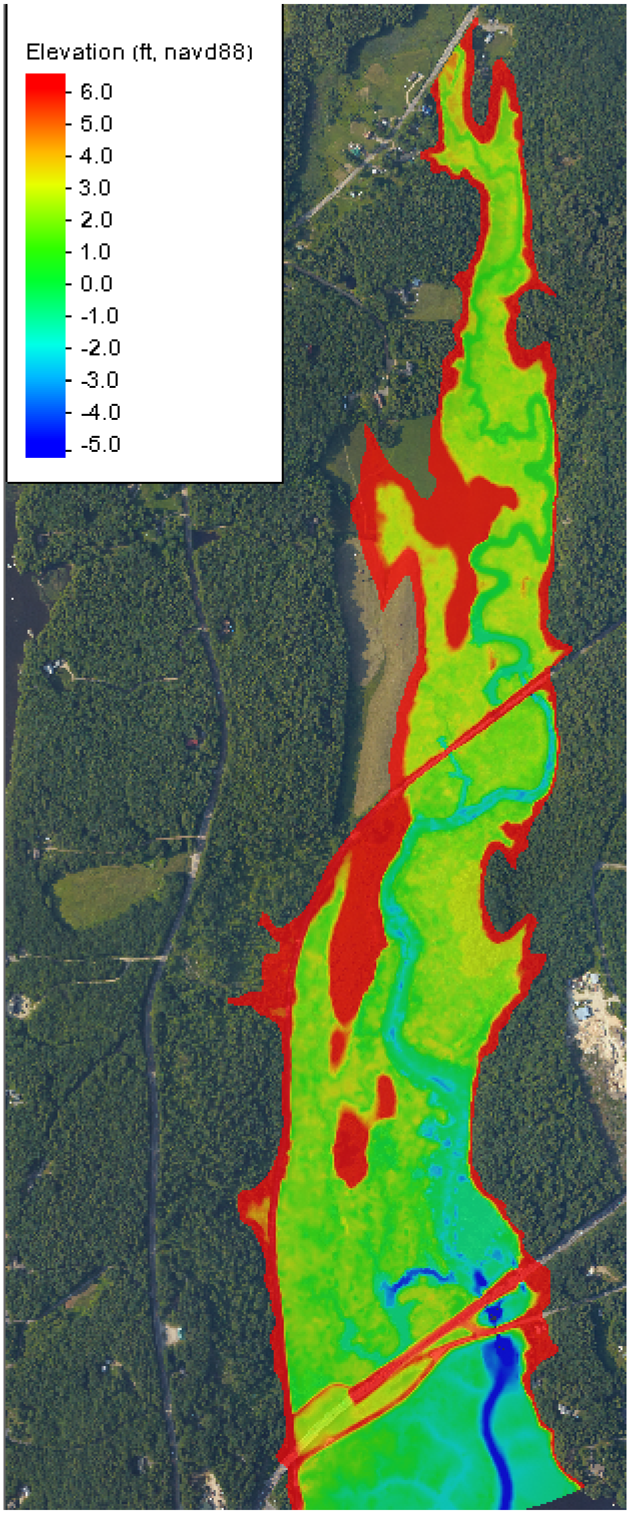


Figure 13 SRH-2D model mesh topography and bathymetry for Back River Marsh

3.2.3 Hydraulic Structures

The primary hydraulic structures located within the marsh system were included in model. Six culverts were included in the model, with each culvert being input into the model as a one-dimensional (1-D) structure. 1-D culverts in SRH-2D are defined using the HY-8 program, with input and output flows being coupled from HY-8 to the overall SRH-2D model domain. Table 2 shows the structure sizes and parameters input into HY-8 for the existing conditions simulations. Structure parameters were obtained from Wood Hole Group's survey of the site, as well as through careful analysis of multiple engineering plans of the old culverts and previous reports of the site. Figure 14 shows the location of each of the culverts included.

Table 2 Culvert Parameters

ID	Culvert Type	Opening Size	Length	Upstream Invert (ft navd88)	Downstream Invert (Ft navd88)
GWR	Concrete Box	10 ft x 4 ft	43 ft	-2.6	-3.2
US-1 East	Concrete Pipe	8 ft diameter	104 ft	-1.0	-2.7
US-1 Middle	Concrete Pipe	6 ft diameter	96 ft	-2.6	-2.8
US-1 West	Corrugated Aluminum Pipe	4 ft diameter	70 ft	-5.1	-4.8
RR East	Granite Block Box	7.5 ft x 6.5 ft	70 ft	-2.9	-2.3
RR West	Concrete Box	3 ft x 2.75 ft	35 ft	-1.2	-0.2

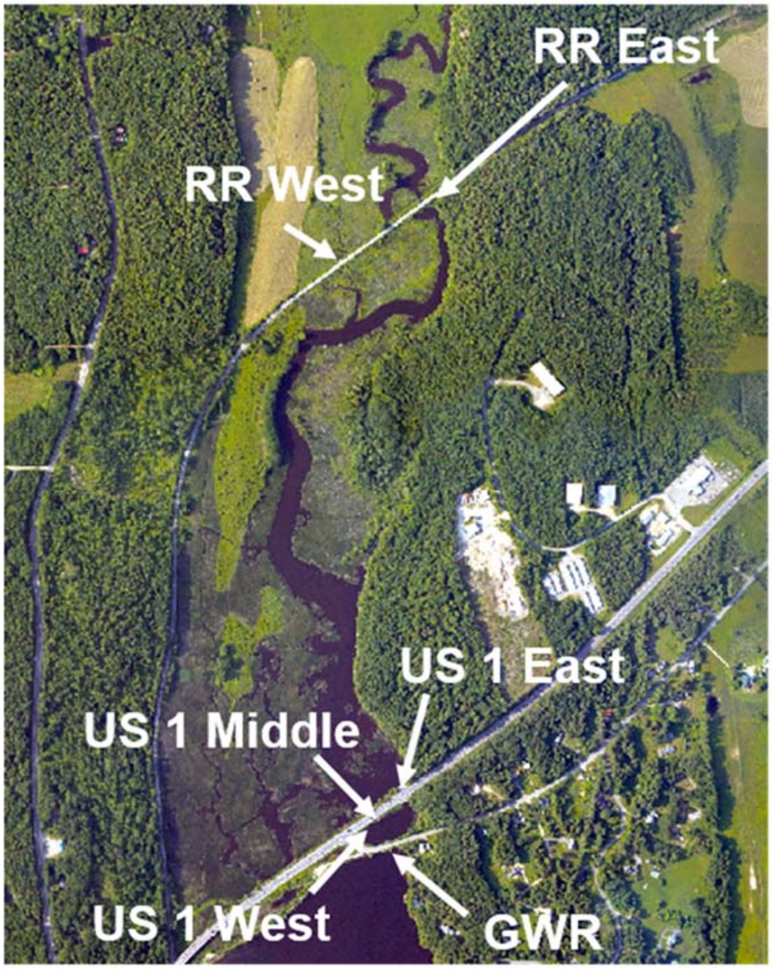


Figure 14 Location of 6 culverts simulated in SRH-2D model of Back River Marsh

3.2.4 Model Calibration

After completion of model setup, the model was calibrated to the measured water level data collected by Woods Hole Group. Model calibration is the process in which model parameters are systematically adjusted through a range of acceptable values and results are examined using standard measures of error to determine the configuration of model parameters that provide the best agreement between modeled variables and observed measurements. Boundary conditions for the hydrodynamic model were specified at two (2) locations as follows: 1) a water level boundary at the Pleasant Cove boundary of the model using the measured time series of water surface elevation (WSE) from the BR1 tide gauge, and 2) a time constant freshwater discharge from Back River Creek, downstream of the ME-127 culverts, with a value of 1.0 cubic feet per second (cfs) based upon USGS streamstats regressions for the project area (Ries et al., 2004). The time constant discharge value for Back River Creek was adjusted several times by trial and error because no measured data was available for the calibration time period. The value used for all calibration simulations resulted in the best calibration statistics for water level station BR6. The model was calibrated for the entire period of collected data (34 days) to allow for model comparisons during both spring and neap tidal cycles.

The model was tested at the six water level station locations within the marsh (BR1 - BR6). The model performance was evaluated by comparing the observed water levels at each station with the modeled values. Time series plot comparisons for the final calibration are shown in Figures 15 through 20.

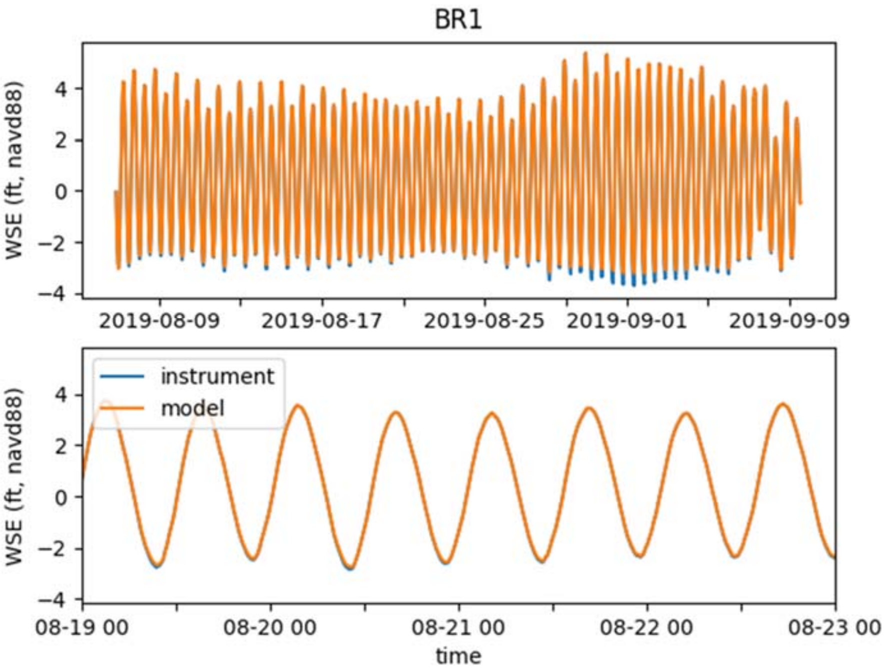


Figure 15 **Comparison of modeled and measured water levels for the calibration period at Station BR1**

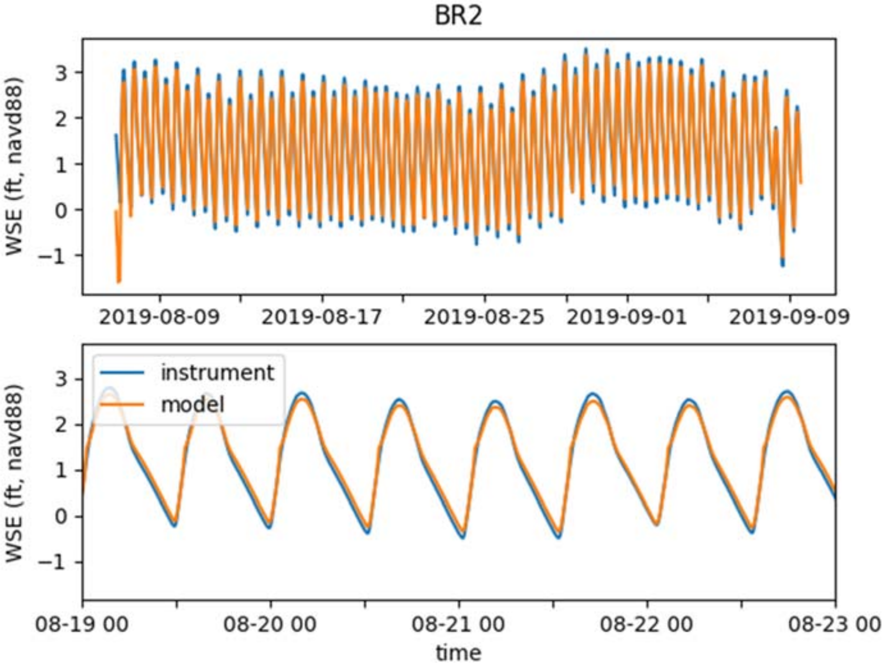


Figure 16 Comparison of modeled and measured water levels for the calibration period at Station BR2

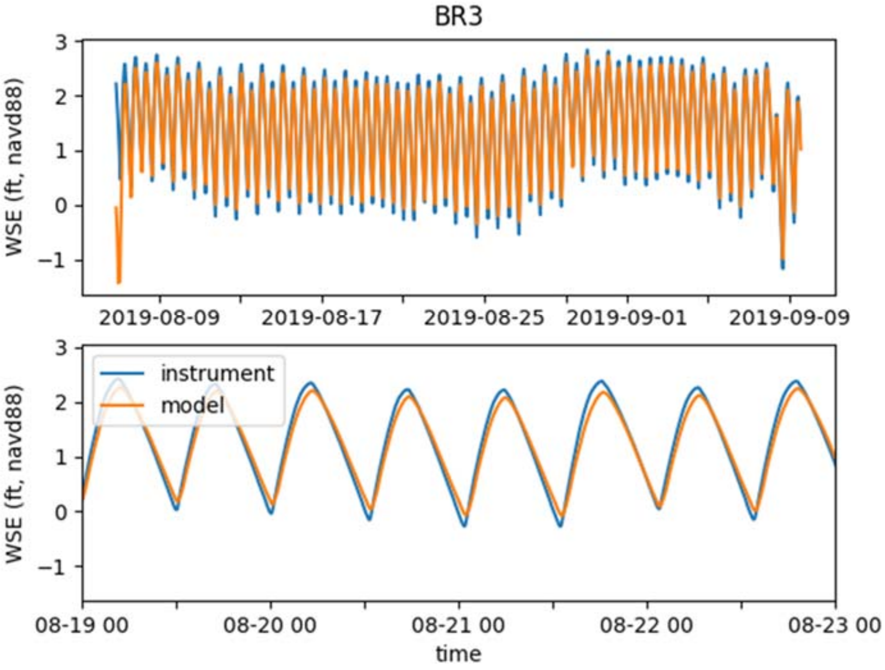


Figure 17 Comparison of modeled and measured water levels for the calibration period at Station BR3

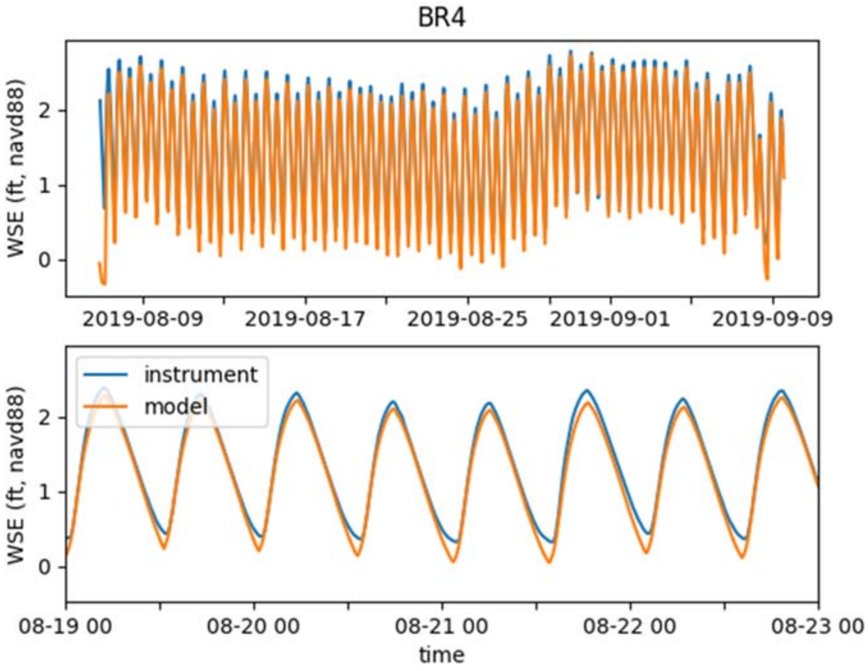


Figure 18 Comparison of modeled and measured water levels for the calibration period at Station BR4

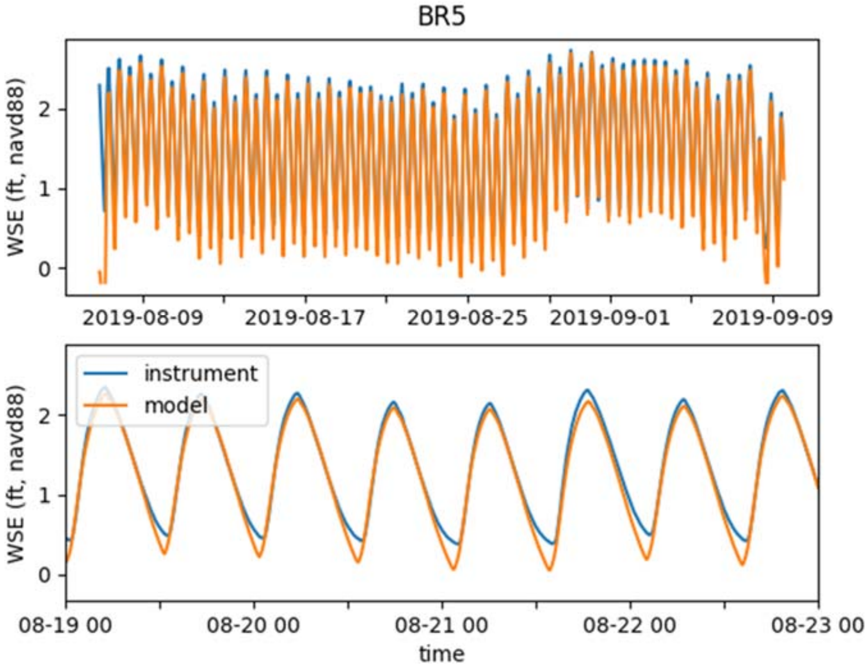


Figure 19 Comparison of modeled and measured water levels for the calibration period at Station BR5

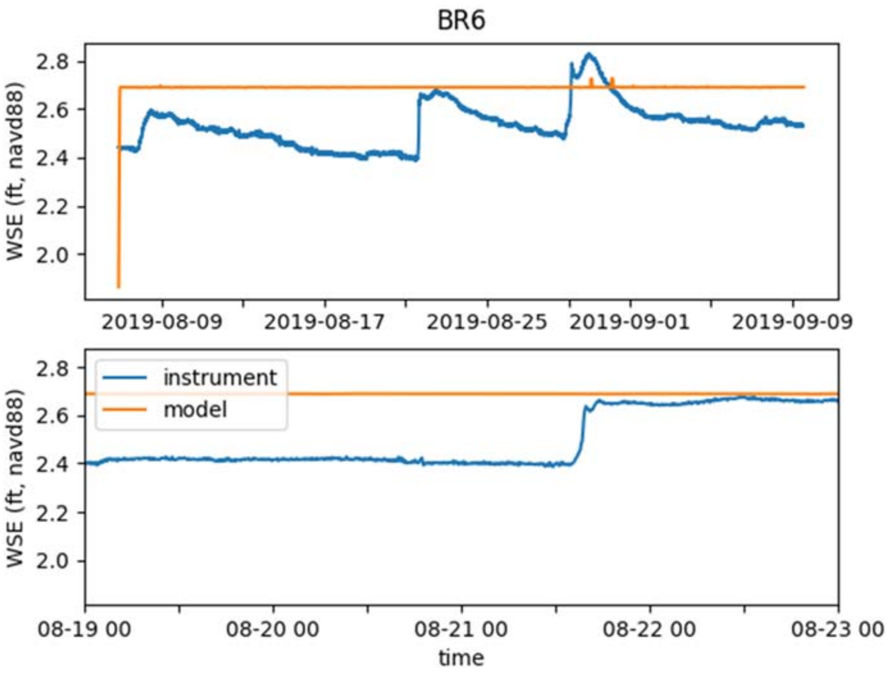


Figure 20 Comparison of modeled and measured water levels for the calibration period at Station BR6

In addition to the visual comparison provided by the time series plots, statistical model error parameters were calculated including Bias, Root Mean Square Error (RMSE), and relative error based on discrete modeled and observed values from the time series. The Bias, RMSE, and relative error are calculated as follows:

$$Bias = \frac{\sum_{1}^{n}\left(p_{\mathrm{mod}} - P_{obs}\right)}{n} \qquad (1)$$

$$RMSE = \sqrt{\frac{\sum_{1}^{n}\left(p_{\mathrm{mod}} - p_{obs}\right)^{2}}{n}} \qquad (2)$$

$$\boldsymbol{Relative\ Error} = \frac{\overline{\boldsymbol{P_{mod}}} - \overline{\boldsymbol{P_{obs}}}}{\overline{\boldsymbol{P_{obs}}}} \qquad (3)$$

where P_{mod} and P_{obs} are the modeled and observed values respectively and *n* is the number of discrete values in the time series.

The bias provides a measure of how close on average the modeled results are to the observed data. A positive value indicates that the model is over-predicting the observation, while a negative value indicates that the model is under-predicting the observations; a bias of zero indicates that, on average, the model accurately reproduces the observations. As such, a low bias value indicates the model is simulating the observed data reasonably. The RMSE is an average of the magnitude of the error. RMSE is always positive with smaller values indicating better model performance.

The error parameters for the Back River Marsh calibration are shown in Table 3. These data indicate a good comparison between the modeled and observed data at the six calibration points during both spring and neap cycles of tide (RMSE less than 3 inches) and that the model can be applied to represent the relative changes expected from the various alternatives evaluated. The U.S. EPA gives technical guidance on error statistic criteria for calibrating estuarine water quality models (EPA, 1990). In these guidelines, relative errors computed for hydrodynamic model variable (e.g., water surface elevation) should be less than 30% in order to achieve adequate calibration. The relative errors associated with the Back River Marsh model are well below these EPA guidelines (6.06% at the highest) and the visual comparisons also indicate the model is well calibrated for existing conditions and can be utilized for the assessment of different scenarios and alternatives.

Table 3 Error statistics for the Back River Marsh observation stations

	RMSE (ft)	Bias (ft)	Relative Error
BR1	0.08	0.03	5.14%
BR2	0.13	0.04	3.20%
BR3	0.15	-0.02	1.73%
BR4	0.10	-0.07	5.02%
BR5	0.10	-0.06	3.74%
BR6	0.18	0.15	6.06%

4.0 PREFERRED ALTERNATIVE

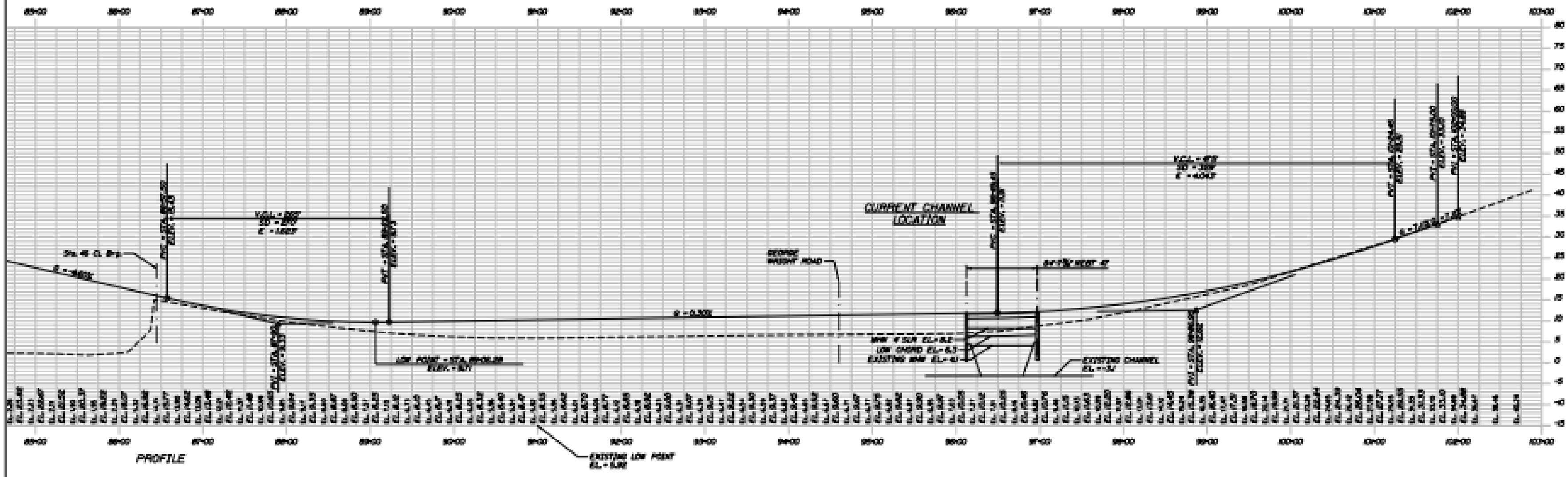
Conceptual design simulations were first conducted for the proposed Route 1 structure over Pleasant Cove which showed that an opening with an invert set at -3.1 feet and a width of 60 feet would meet the restoration goals for the upstream marsh. Based on these simulations, the Project Team developed a preferred alternative design for the Pleasant Cove US-1 Bridge that would tie into plans for the Station 46 bridge. This preferred design included a slightly larger opening than that found to provide full tidal transparency during the conceptual design simulations (due to its trapezoidal shape), as well as raising US-1 where it crosses Back River Marsh to provide additional resiliency to the roadway. The current roadway has a centerline low point of approximately 5.9 ft close to where it meets the station 46 bridge, and the lower portions of the road have been subject to flooding in recent storm events (Woods Hole Group, 2021). The preferred alternative raises the roadway such that the minimum elevation of the road where it crosses Back River Marsh is at approximately 9.7 ft.

Figure 21 shows a graphic of the preferred alternative design provided by MaineDOT's design consultant (HNTB, Westbrook, ME). The top of the opening was set at 5.9 ft (2 ft higher than the present day MHW in Pleasant Cove), and the bottom of the opening was set at an invert of -3.1 ft to mimic the natural channel. For evaluating the preferred alternative, it is assumed that the George Wright Road crossing will be opened/reconstructed to facilitate full tidal flow to the upstream marsh. To this effect, a 75-ft wide opening with a -4 ft, NAVD88 invert was inserted into the alternative model simulations at George Wright Road.

A number of additional scenarios were simulated using the Back River Marsh SRH model to assess how the preferred alternative would perform under a range of tidal and storm conditions. To simulate the alternative design, the topography of the newly proposed roadway was interpolated onto the model mesh. In addition, the opening was simulated as a 2-dimensional opening with pressurized flow boundaries at both the upstream and downstream portions of the opening. This boundary type in SRH allows for 2-dimensional modeling of hydraulic structures. A top height of the opening can be specified as well as an overtopping height to allow for flow over the roadway. This option allowed for more accurate modeling of the preferred design in comparison to the 1-D structure types used in the existing and conceptual simulations. This was especially important in this case where the preferred design had a hydraulic opening with a trapezoidal shape.

ALTERNATIVE 2 - 4' RAISE OF PROFILE:

- Existing Roadway Low Point = El. 5.92
- Proposed Roadway Low Point = El. 9.71
- Maximum Profile Increase = 4.7 ft.
- Minimum Roadway Grade = 0.3%
- Existing MHW Elevation = 4.1
- MHW Elevation w/ 2' SLR = 6.1
- MHW Elevation w/ 4' SLR = 8.2



BRIDGE CHARACTERISTICS:

Bridge in Current Channel Location

- Maximum Profile Increase at Bridge = 4.7 ft.
- Low Chord Elevation = 6.3
- Freeboard reported over MHW assuming 0.5 ft waves.
  - Freeboard on Opening Day = 1.7 ft.
  - Freeboard w/ 2' SLR = -0.3 ft.
  - Freeboard w/ 4' SLR = -2.4 ft.

Figure 21 Preferred alternative design provided by MaineDOT.

4.1 Preferred Alternative MaineDOT Hydraulic Design scenarios

To ascertain the performance of the preferred alternative under a wide range of possible conditions, twelve (12) scenarios were simulated with the preferred alternative in place. These hydraulic design scenarios generally correspond to scenarios identified in the MaineDOT Bridge Design Guide for spans over tidal waters. The intent is to assess extreme flow conditions that might lead to overtopping, scour and other potentially hazardous and damaging situations. The following 12 model runs were completed for the preferred alternative:

- Typical tides (15-day simulation)
- Typical tides with 2 ft SLR (15-day simulation)
- Typical tides with 4 ft SLR (15-day simulation)
- 50-year coastal surge event (3-day simulation)
- 50-year coastal surge event with 2 ft SLR (3-day simulation)
  50-year coastal surge event with 4 ft SLR (3-day simulation)
- Typical tides w/ a 50-year return period freshwater discharge (3-day simulation)
- Typical tides w/ a 50-year return period freshwater discharge & 2 ft SLR (3-day simulation)
- Typical tides w/ a 50-year return period freshwater discharge & 4 ft SLR (3-day simulation)
- Typical tides w/ a 100-year return period freshwater discharge (3-day simulation)
- Typical tides w/ a 100-year return period freshwater discharge & 2 ft SLR (3-day simulation)
- Typical tides w/ a 100-year return period freshwater discharge & 4 ft SLR (3-day simulation)

Water levels from the last 15 days of the 33-day tidal measurements in Pleasant Cove were selected as the typical tide boundary conditions for these simulations as this period encompassed the higher spring tides. SLR was linearly combined with the tidal and storm boundaries to create SLR scenarios. Extreme return frequency freshwater discharge values were obtained from the USGS streamstats regressions for the Back River Marsh area (Ries et al., 2004) and the values utilized are listed in Table 7. The streamstats values were obtained from the upstream boundary of the SRH model domain, directly downstream of where Back River Creek crosses ME-127 (Middle Rd).

Table 7 **Extreme peak flow discharge values for Back River Creek, downstream of ME-127 obtained from USGS's Streamstats.**

Storm Event	Peak Flow (cfs)
50-Year	187
100-Year	219

Low frequency surge events causing extreme water levels in Pleasant Cove were obtained from Federal Emergency Management Agency's (FEMA) Flood Insurance Study (FIS) for Sagadahoc County, ME. The FIS included annual-exceedance-probability[2] (AEP) stillwater[3] elevations established from a pre-county-wide flood insurance study. The FIS utilized flood frequency information developed by the U.S. Army Corps of Engineers (USACE) for tidal flood profiles along the the New England coastline (USACE New England Division, 1980), as well as results from a one-dimensional (1-D) estuarine storm surge model that simulated tidal flooding for the region and computed percent-annual-chance surge elevations (New England Coastal Engineers Inc., 1977). The FEMA FIS report considered the relative influence of coastal flooding versus riverine flooding throughout Sagadahoc County.

The FIS provides AEP stillwater elevations for a location 4,000 feet upstream of the Upper Hell Gate, within the Sasanoa River (closest point to Pleasant Cove). The AEP stillwater elevations were extracted from the FIS for the following return periods: 10-year, 50-year, 100-year, and 500-year events.

Table 8 **AEP coastal stillwater elevations (FEMA, 2015).**

Return Period (yrs.)	AEP (%)	Stillwater Elevation (Ft NAVD88)
10	10	8.3
50	2	9.1
100	1	9.3
500	0.2	10

A peak extreme stillwater elevation for a 50-year return period storm of 9.1 ft relative to NAVD88 was utilized as a boundary condition for all coastal surge event simulations to drive water levels

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[2] Annual-exceedance-probability indicates the probability that a water level will be exceeded in any given year. It can be related to return period, T, using the relationship: AEP (%) = 1/T*100%. So, a 50-year return period storm has an AEP of 2%.

[3] Coastal stillwater elevations listed in the FEMA's FIS include storm surge and tides. These elevations can also include wave setup, but the location of interest is too far inland to have effects of wave setup.

at the Pleasant Cove model boundary. This peak water level was superimposed onto a typical tidal signal to develop a synthetic storm surge hydrograph using methods detailed in the 2004 Federal Highway Administration Hydraulic Engineering Circular No. 25. The storm surge hydrograph developed using this procedure for a 50-year storm event is shown in Figure 22.

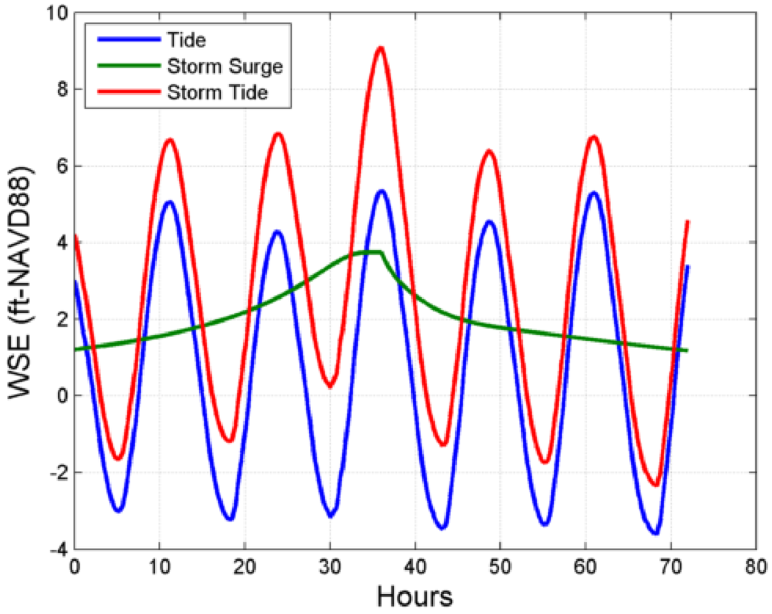

Figure 22. **Storm surge hydrograph developed for the 50-year storm event with no SLR for Back River Marsh SRH model**

4.2 PREFERRED ALTERNATIVE SIMULATION RESULTS

4.2.1 Tidal Simulation Results

The preferred alternative was assessed during typical tidal conditions as well as tidal conditions with both 2 ft and 4 ft of SLR in order to determine what changes might be expected to occur relative to existing conditions. Each simulation was conducted for the 15-day period corresponding to the spring tides in the tidal cycle to allow for direct comparison to the existing conditions results. Figures 23, 24 and 25 show time series results for each of the simulations at four water level stations throughout the marsh. The alternative results demonstrate both tidal transparency upstream of US-1 in Back River Marsh (station BR3), as well as increased drainage in that portion of the marsh relative to existing conditions. Increased drainage and high water datum elevations are also shown upstream of the railroad crossing (station BR5), but both are restricted by the culverts located there as well as the channel geometry throughout the lower marsh basin.

Table 9 shows the tidal datums for the preferred alternative tidal scenarios for all the water level stations. Flood extent/depth maps for a spring high tide and the storm scenarios for the preferred alternative are shown in Appendix A of this report.

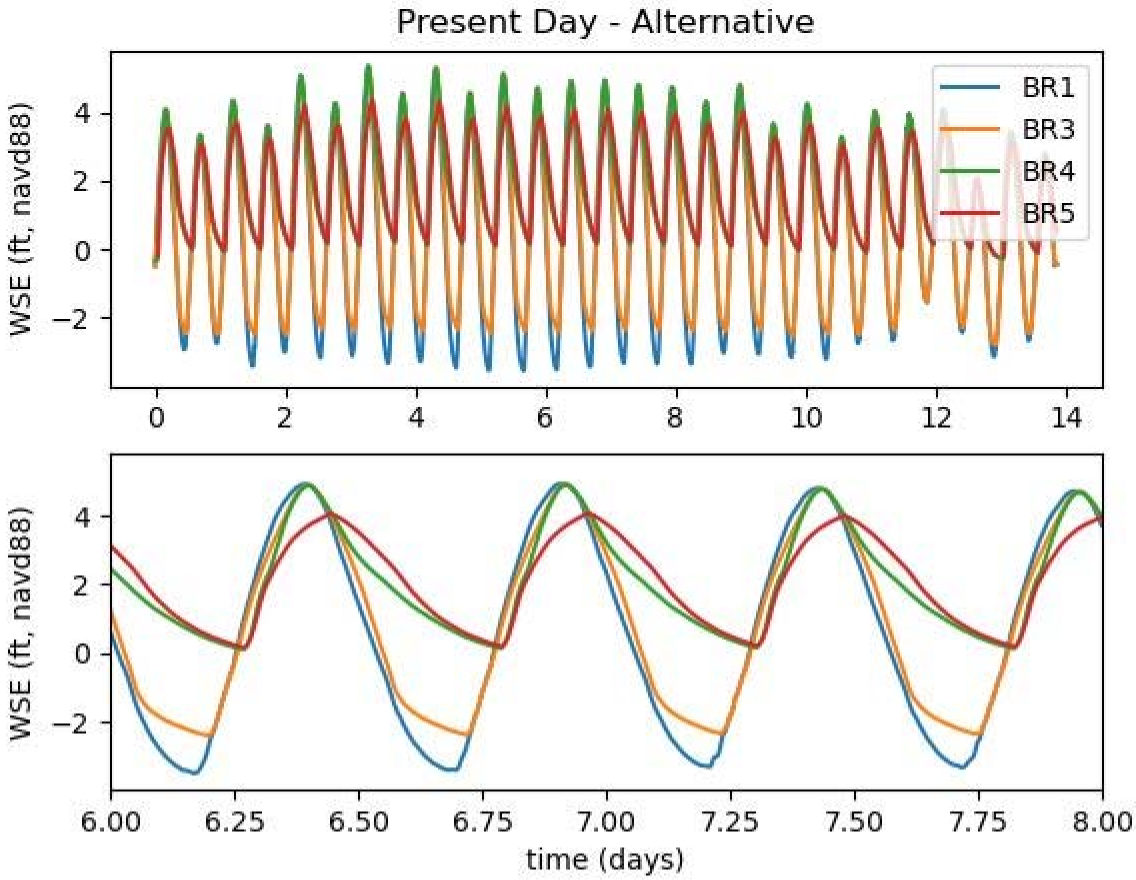

Figure 23 **Present day preferred alternative tidal simulation water surface elevation time-series results.**

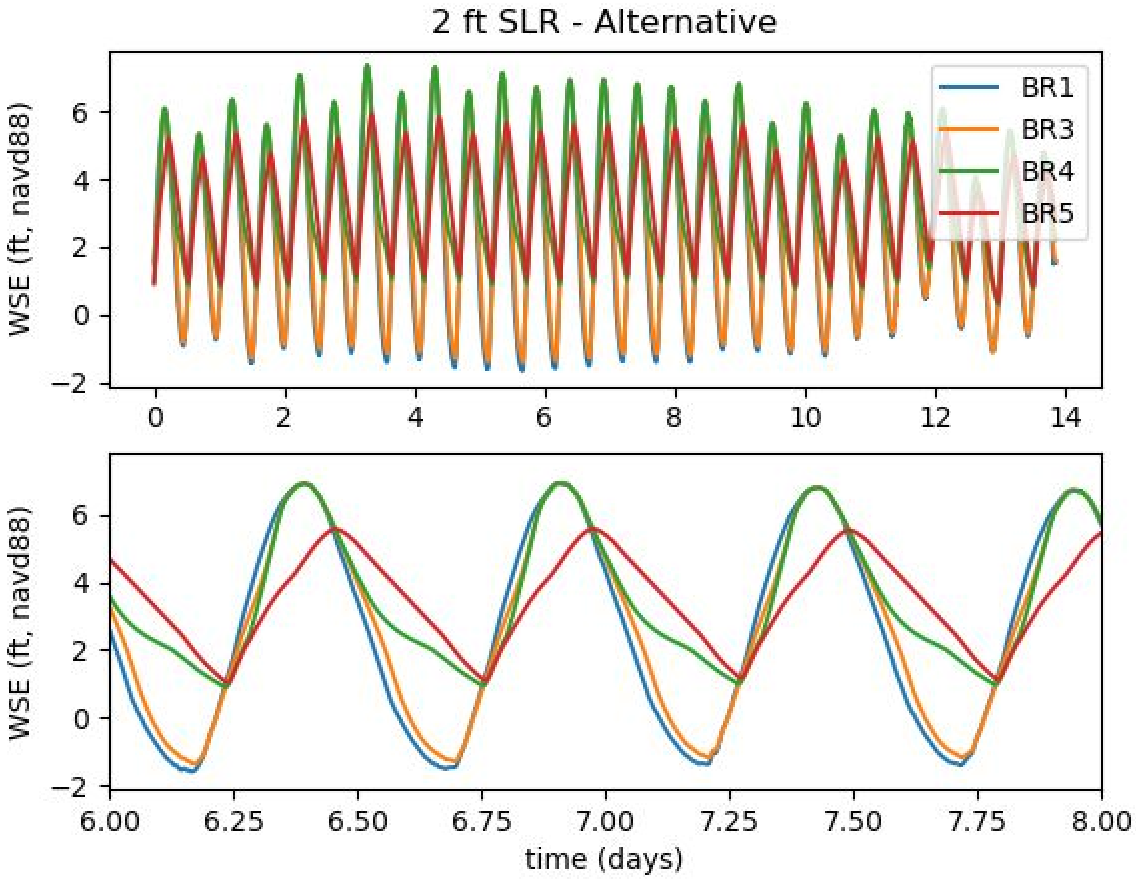

Figure 24 Preferred alternative tidal simulation with 2 ft of SLR water surface elevation time-series results.

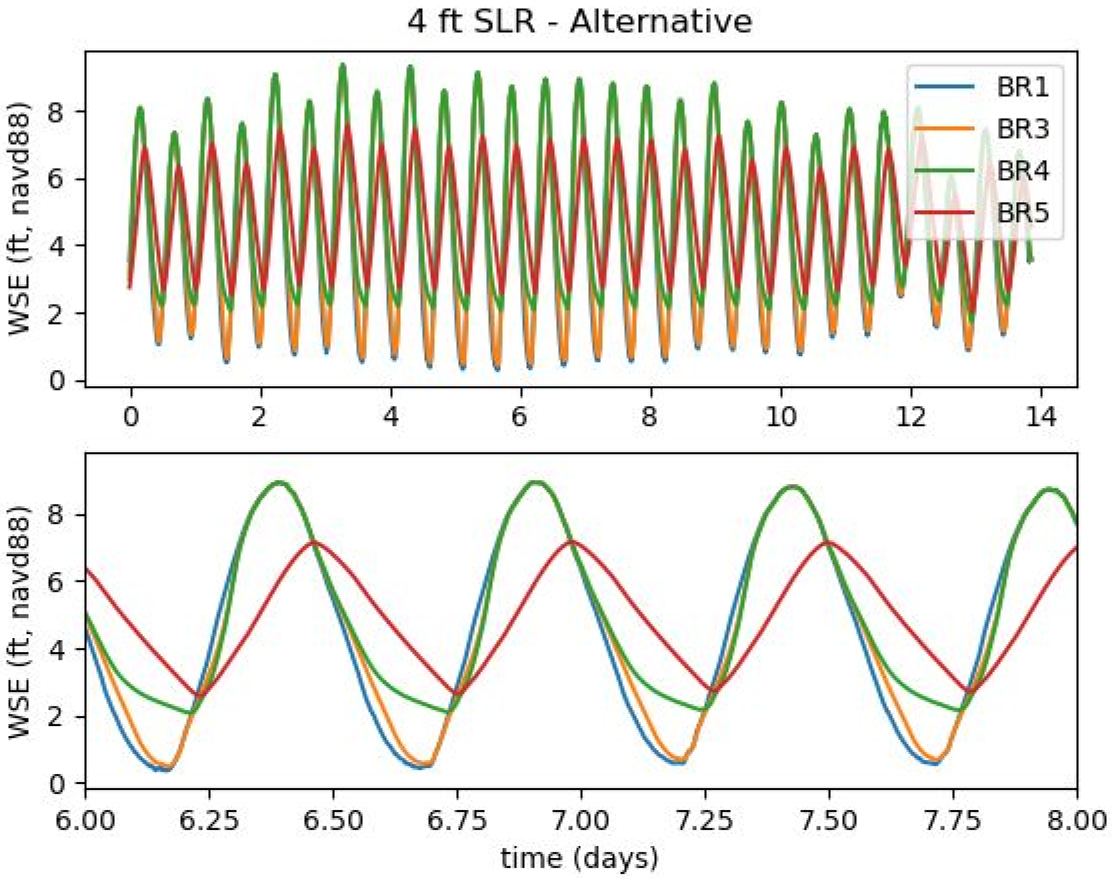

Figure 25 **Preferred alternative tidal simulation with 4 ft of SLR water surface elevation time-series results.**

Table 9 **Tidal Datums for Preferred Alternative Tidal Scenarios, in feet relative to NAVD88**

Preferred Alternative (No SLR) - 15 Day Simulation						
	BR1	**BR2**	**BR3**	**BR4**	**BR5**	**BR6**
MLLW	-3.2	-3.1	-2.4	0	0.1	2.7
MLW	-3	-2.9	-2.3	0	0.1	2.7
MTL	0.6	0.7	1	2.1	1.9	3.2
MHW	4.2	4.2	4.2	4.2	3.6	3.6
MHHW	4.6	4.6	4.6	4.5	3.9	3.9
Preferred Alternative (2ft SLR) - 15 Day Simulation						
	BR1	**BR2**	**BR3**	**BR4**	**BR5**	**BR6**
MLLW	-1.2	-1.2	-1	0.8	1	2.7
MLW	-1	-1	-1	0.9	1	2.7
MTL	2.6	2.6	2.7	3.6	3.2	4
MHW	6.2	6.2	6.2	6.2	5.2	5.2
MHHW	6.6	6.6	6.6	6.6	5.5	5.5
Preferred Alternative (4ft SLR) - 15 Day Simulation						
	BR1	**BR2**	**BR3**	**BR4**	**BR5**	**BR6**
MLLW	0.7	0.8	0.9	2.1	2.6	2.8
MLW	0.9	1	1	2.2	2.7	2.8
MTL	4.6	4.6	4.7	5.3	4.8	4.9
MHW	8.2	8.2	8.2	8.2	6.9	6.9
MHHW	8.6	8.6	8.6	8.6	7.1	7.1

4.2.2 Storm Simulation Results

Three different storm scenarios were simulated for three SLR scenarios (9 storm simulations) in order to ascertain the performance of the preferred alternative under a range of extreme conditions. Table 10 shows the maximum water levels at each of the 6 water level stations that occur over the course of each storm scenario in comparison to the maximum water levels observed during the regular tidal scenario.

Table 10 Maximum water levels observed at water level stations for preferred alternative simulations, in feet relative to NAVD88

	Present Day	2 ft SLR	4 ft SLR	Present Day	2 ft SLR	4 ft SLR
	Typical Tides			**50 Year Surge Event**		
BR1	5.4	7.4	9.4	9.1	11.1	13.1
BR2	5.3	7.4	9.4	9.1	11.1	13.1
BR3	5.3	7.3	9.3	9.1	11.1	13.1
BR4	5.3	7.4	9.4	9.1	11.1	13.1
BR5	4.4	5.9	7.6	7.1	10.6	13.1
BR6	4.4	5.9	7.6	7.1	10.6	13.1
	50 Year Freshwater Discharge Event			**100 Year Freshwater Discharge Event**		
BR1	5.4	7.4	9.4	5.4	7.4	9.4
BR2	5.3	7.4	9.4	5.4	7.4	9.4
BR3	5.3	7.4	9.4	5.3	7.4	9.4
BR4	5.4	7.4	9.4	5.4	7.4	9.4
BR5	5.2	6.8	8.5	5.3	6.9	8.7
BR6	5.3	6.8	8.6	5.4	7.0	8.7

The results show that with the preferred alternative, under a 50-year return period surge condition, peak water levels in the marsh are equal to the maximum water levels in Pleasant Cove up to the railroad crossing in the present day and 2 ft SLR scenarios. Peak water levels are slightly reduced upstream of the railroad under these scenarios (compared to downstream). The low point of Route 1 is exceeded in a 50-year surge event with 2 ft of SLR. Under the 4 ft SLR condition, the peak water level in the upper marsh matches that in Pleasant Cove due to overtopping of the railroad crossing. The two extreme freshwater discharge scenarios cause increased water levels upstream of the railroad, however there are no impacts to the railroad crossing and there are limited impacts downstream of the railroad in the lower Back River Marsh basin in terms of maximum water levels. Maximum flood extent maps of all preferred alternative scenarios are shown in the appendix of this report.

4.2.3 Current Velocities

To support design work for the preferred alternative at the Rt-1 Pleasant Cove Bridge, as well as the Station 46 bridge, velocity data were extracted at four points located throughout Back River Marsh. This data was made available for use in ascertaining possible impacts of scour at the infrastructure being designed. Figure 26 shows a map of the location of the points where data was extracted. The locations of these points are also listed in Table 11.

Figure 26 **Map of velocity data extraction points for engineering calculations/scour analysis**

Table 11 **Location of velocity data extraction points (horizontal datum NAD83_Maine_CS2000_West_ft)**

Point ID	X	Y
1	1137534.7	398575.1
2	1137610.7	398464.8
3	1136715.5	397808.6
4	1136650.5	397892.4

The maximum velocity magnitudes that were simulated at each of these points is shown in Table 12. These velocities are only valid for the specific points they represent. Velocities can vary spatially significantly. For example, velocities in the proposed Pleasant Cove Bridge opening are slightly higher than those presented here which were obtained just upstream and downstream of the structure.

Table 12 **Maximum velocities in ft/s extracted at points for engineering calculations/scour analysis.**

Maximum Velocities (ft/s)				
	Pt 1	**Pt 2**	**Pt 3**	**Pt 4**
Tides	4.6	4.9	0.6	1.6
Tides (2ft SLR)	5.9	5.5	1.7	1.7
Tides (4ft SLR)	5.6	5.3	1.2	1.5
50q	4.3	5.2	0.4	1.3
50q (2ft SLR)	5.1	5.7	1.1	1.1
50q (4ft SLR)	4.9	5.7	1.5	1.4
100q	4.2	5.2	0.4	1.3
100q (2ft SLR)	5.0	5.8	1.1	1.1
100q (4ft SLR)	4.8	5.7	1.4	1.4
50yr Surge	5.8	6.0	1.6	1.6
50yr Surge (2ft SLR)	5.7	5.7	1.6	1.6
50yr Surge (4ft SLR)	5.0	5.2	1.5	1.6

5.0 SUMMARY AND CONCLUSIONS

This H&H study was primarily focused on: 1) evaluating tidal and extreme storm flow through the proposed US-1 bridge replacement at Pleasant Cove and the Station 46 bridge and 2) providing infrastructure resilience to the roadways crossing the marsh. It was assumed the George Wright Road crossing would also be replaced with a larger opening thereby restoring tidal flow to the lower portion of the Back River marsh (south of the Rockland Branch Railroad crossing),

An initial phase of the study included a field assessment to gain a better understanding of existing conditions within the marsh system. Six tide gauges were deployed to understand the existing tidal dynamics throughout the system. The water levels collected over the 34-day deployment showed a reduction in tide range moving upstream due to the existing hydraulic structures and other natural features.

To further investigate existing conditions and to evaluate possible resilience/tidal crossing alternatives, a 2-D hydrodynamic model (SRH-2D) was developed for the Back River Creek and Marsh system. Key findings with regards to water levels, potential for restoration, added benefits for resiliency, and any secondary adverse impacts are listed as follows:

- Model simulations of typical tides and existing conditions show the tide range upstream of the culverts at US-1 is reduced from that seen Pleasant Cove (reduction in mean high water from 3.9 ft to 2.3 ft). The low tides levels upstream of US-1 are also higher than the low tide levels in Pleasant Cove indicating incomplete drainage of the marsh system. These results confirm the existence of a tidal restriction between Pleasant Cove and the marsh directly upstream of US-1 due to the culverts.

- The results of the SLR simulations of existing conditions show that drainage will continue to be a problem in Back River Marsh with the existing culvert structures. For the spring tides with 2 ft of SLR and all tides with 4 ft of SLR scenario, the peak high tide levels are equivalent between the downstream and upstream sides of US-1, but this is due to water being able to pass under the Station 46 bridge in these scenarios.

- Based on the conceptual design simulations conducted for this project, the Project Team developed a preferred alternative design for US-1 that would tie into plans for the Station 46 bridge. The preferred design is an open span with a top width of approximately 85 feet and bottom width of 50 feet. The channel invert was set at -3.1 feet with a low chord elevation of 6.3 feet. The preferred alternative raises the roadway such that the minimum elevation of the road where it crosses Back River Marsh is at approximately 9.7 ft.

- Model simulations of the preferred alternative show the MHW and MHHW datums upstream of US-1 are increased from 2.4 and 2.5 feet to 4.2 and 4.6 feet, respectively, in present-day (no SLR). The preferred alternative also provides for increased drainage and lower low tides, leading to an increase in the mean tidal range from 2 feet in existing conditions to 6.5 feet in proposed conditions.

- With SLR, there is little difference in the MHW and MHHW datums upstream of US-1 when comparing the preferred alternative with existing conditions. The preferred alternative does provide for more drainage capacity in the SLR scenarios compared with existing conditions, however, which allows for a large tide range to be maintained in the lower basin.

- With the preferred alternative under a 50-year return period surge condition, peak water levels in the lower marsh are equal to that in Pleasant Cove up to the railroad crossing in the present day and 2 ft SLR scenarios. Peak water levels upstream of the railroad are slightly reduced under these scenarios, however, the peak water level in the upper marsh under the 4 ft SLR condition matches that in Pleasant Cove due to overtopping of the railroad crossing.

6.0 REFERENCES

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APPENDIX A: FLOOD DEPTH MAPS FOR SPRING TIDES AND STORM EVENTS

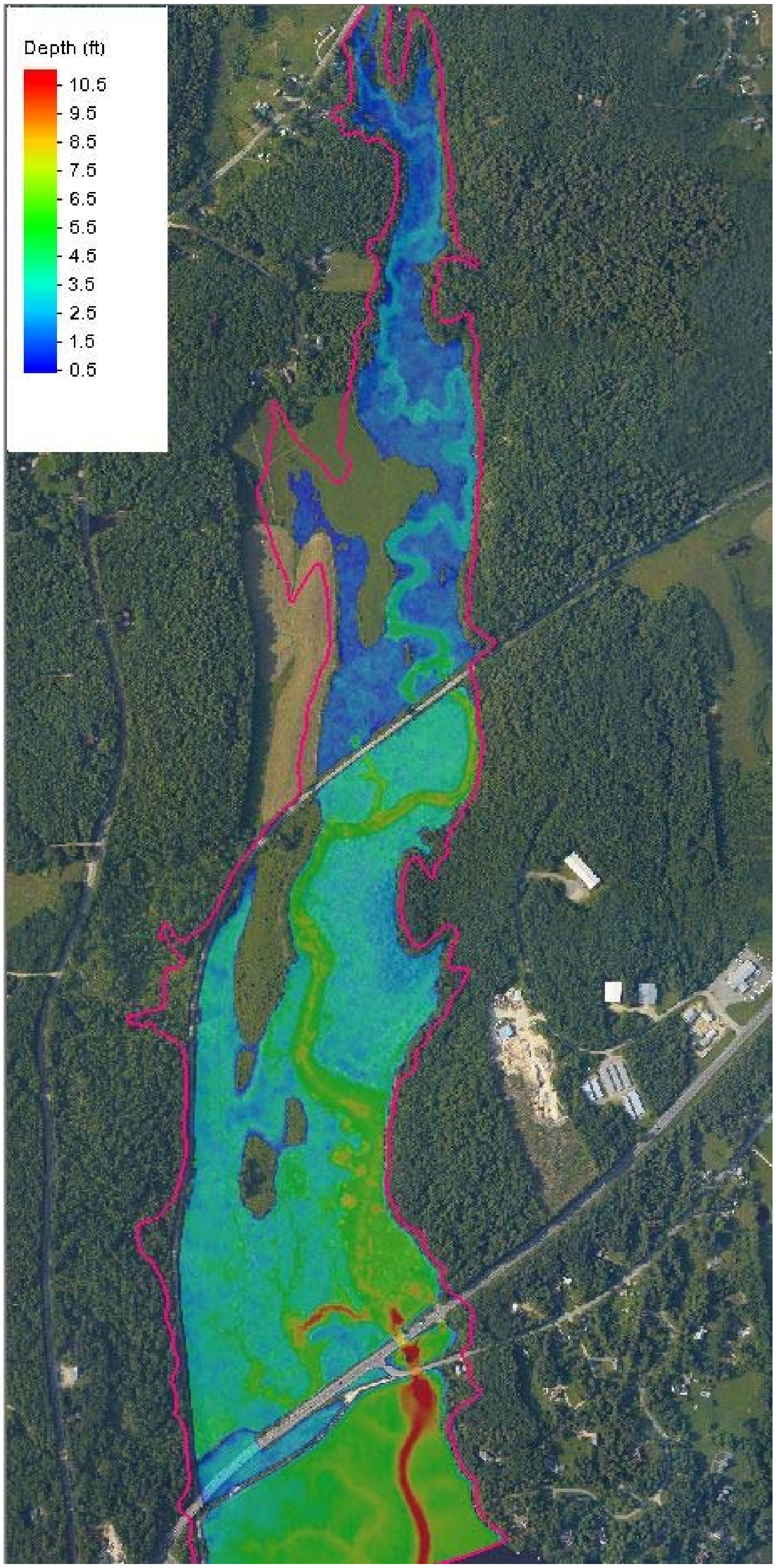

Figure A-1. Preferred Alternative typical tides – Water depths at Spring Tide.

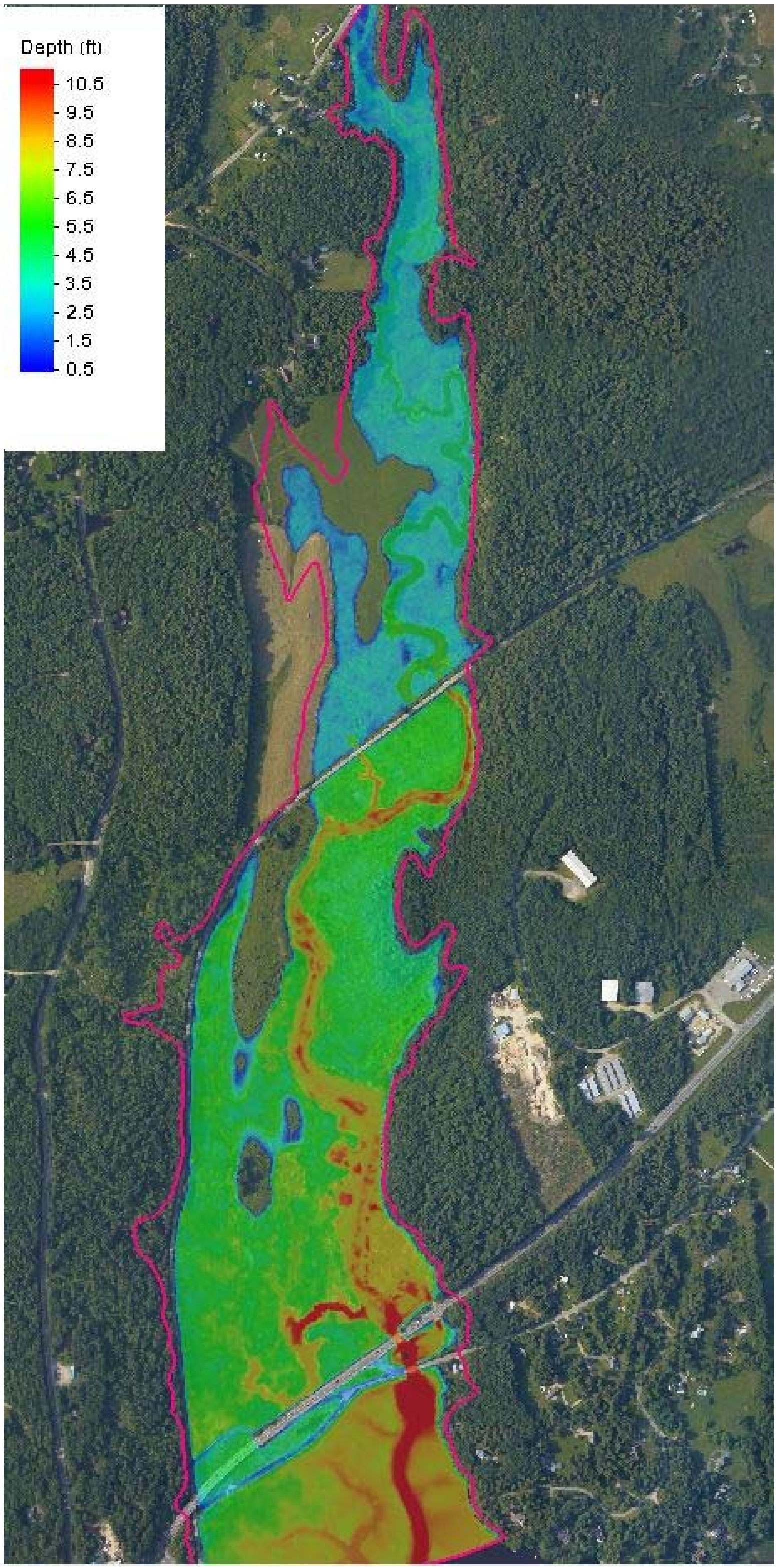

Figure A-2. Preferred Alternative typical tides with 2 ft SLR – Water depths at Spring Tide.

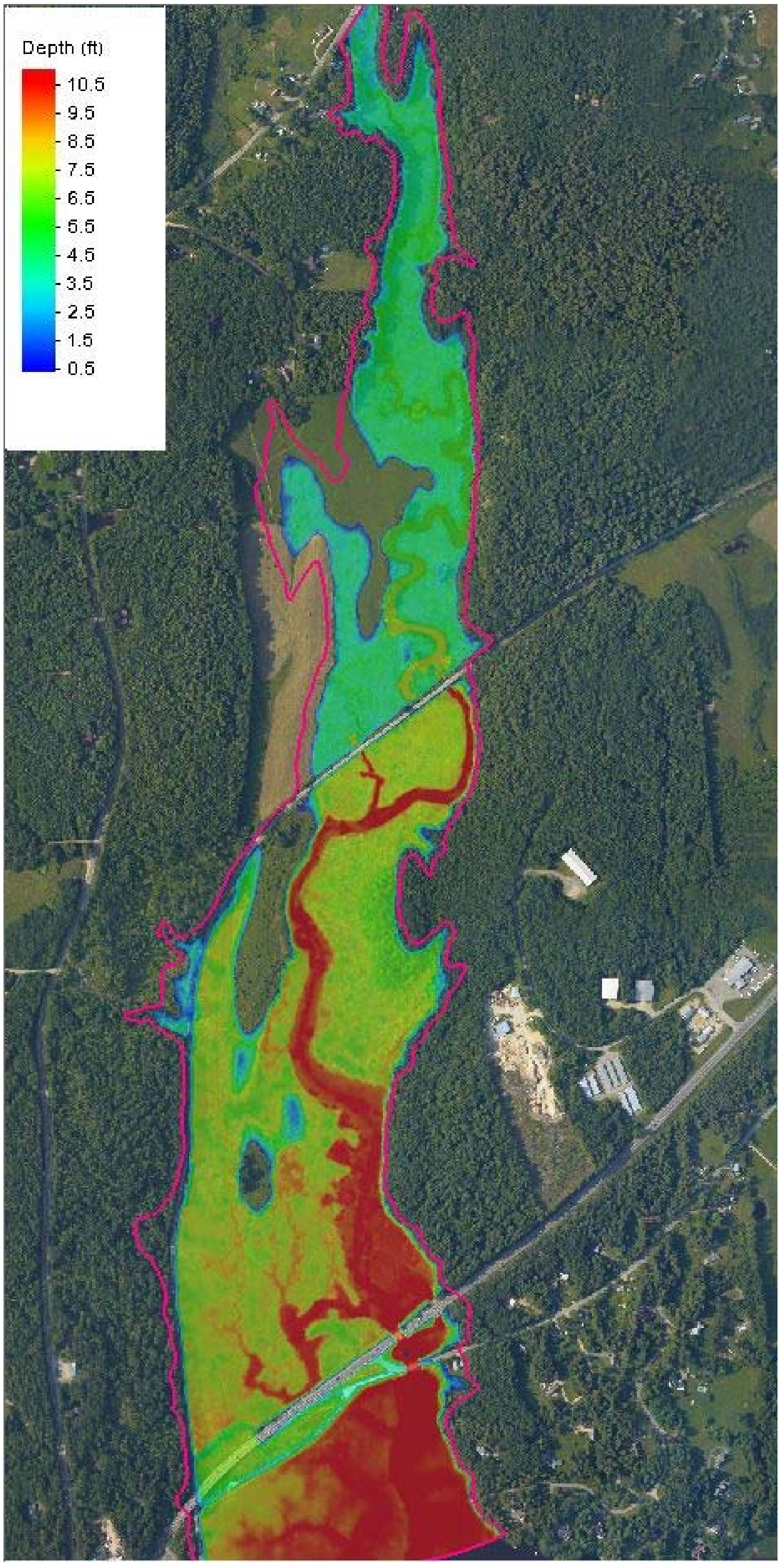

Figure A-3. Preferred Alternative typical tides with 4 ft SLR – Water depths at Spring Tide.

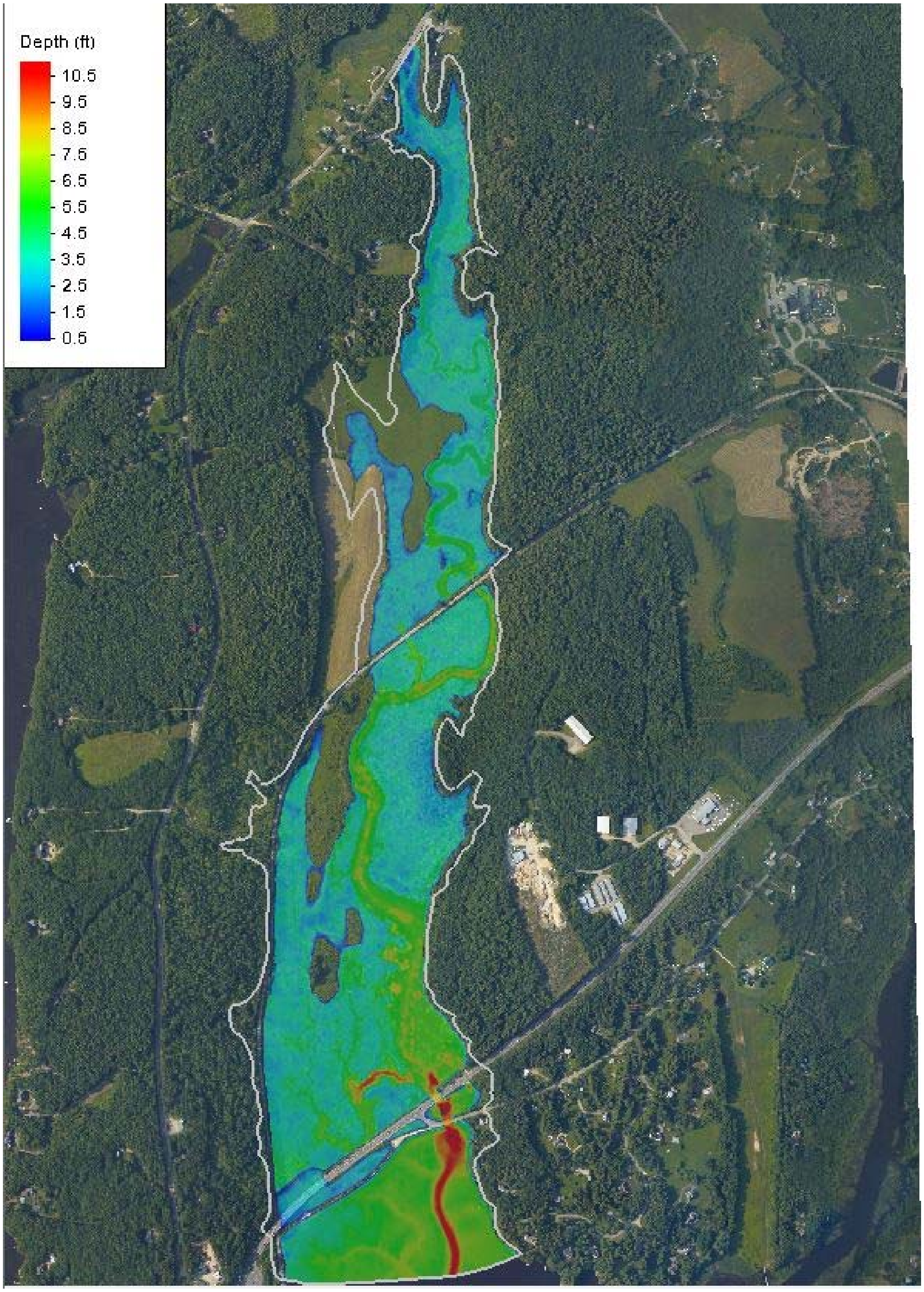

Figure A-4. **Preferred Alternative 50-year return period freshwater discharge with typical tides – Maximum water depths.**

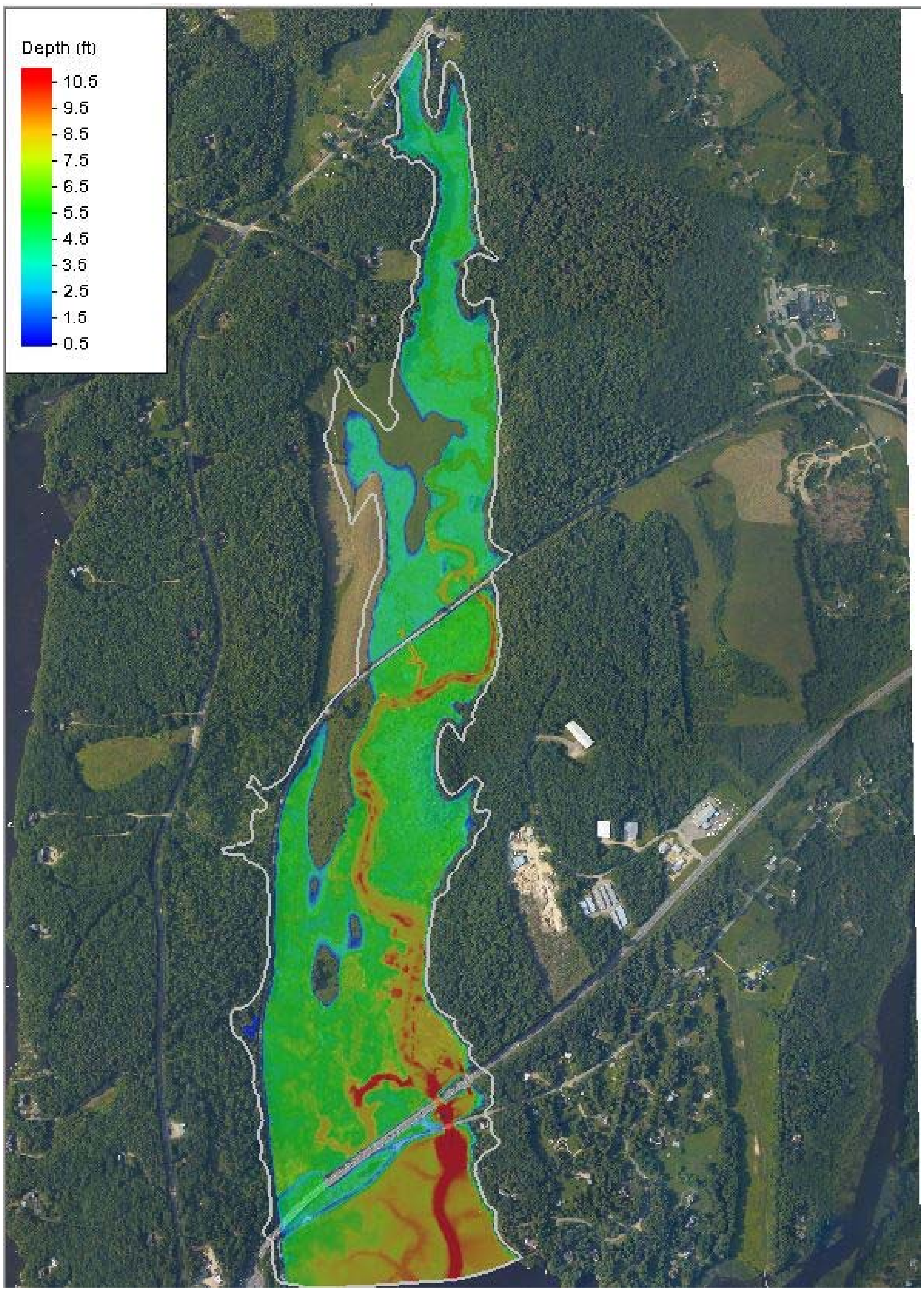

Figure A-5. Preferred Alternative 50-year return period freshwater discharge with typical tides with 2 ft SLR – Maximum water depths.

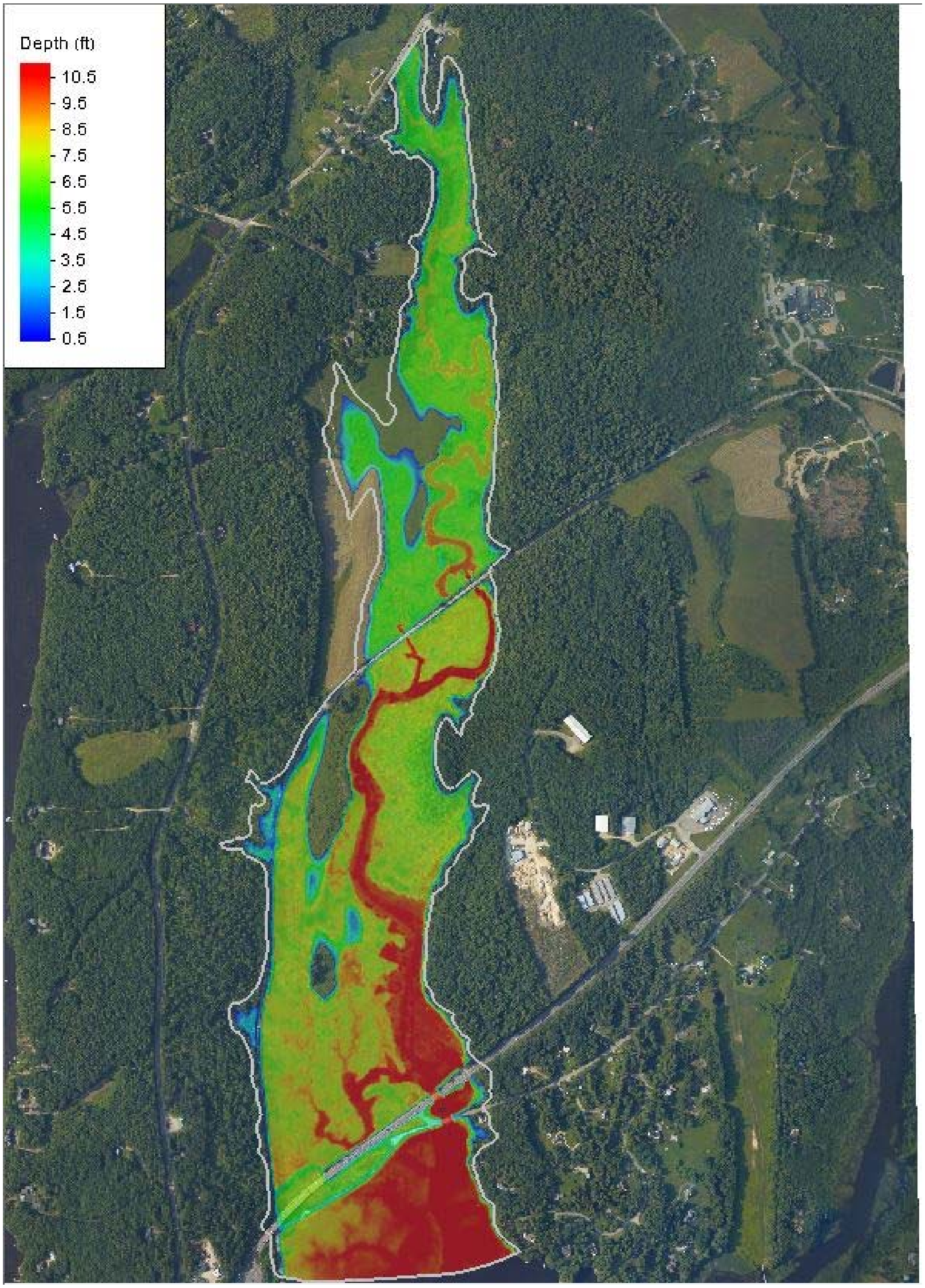

Figure A-6. **Preferred Alternative 50-year return period freshwater discharge with typical tides with 4 ft SLR – Maximum water depths.**

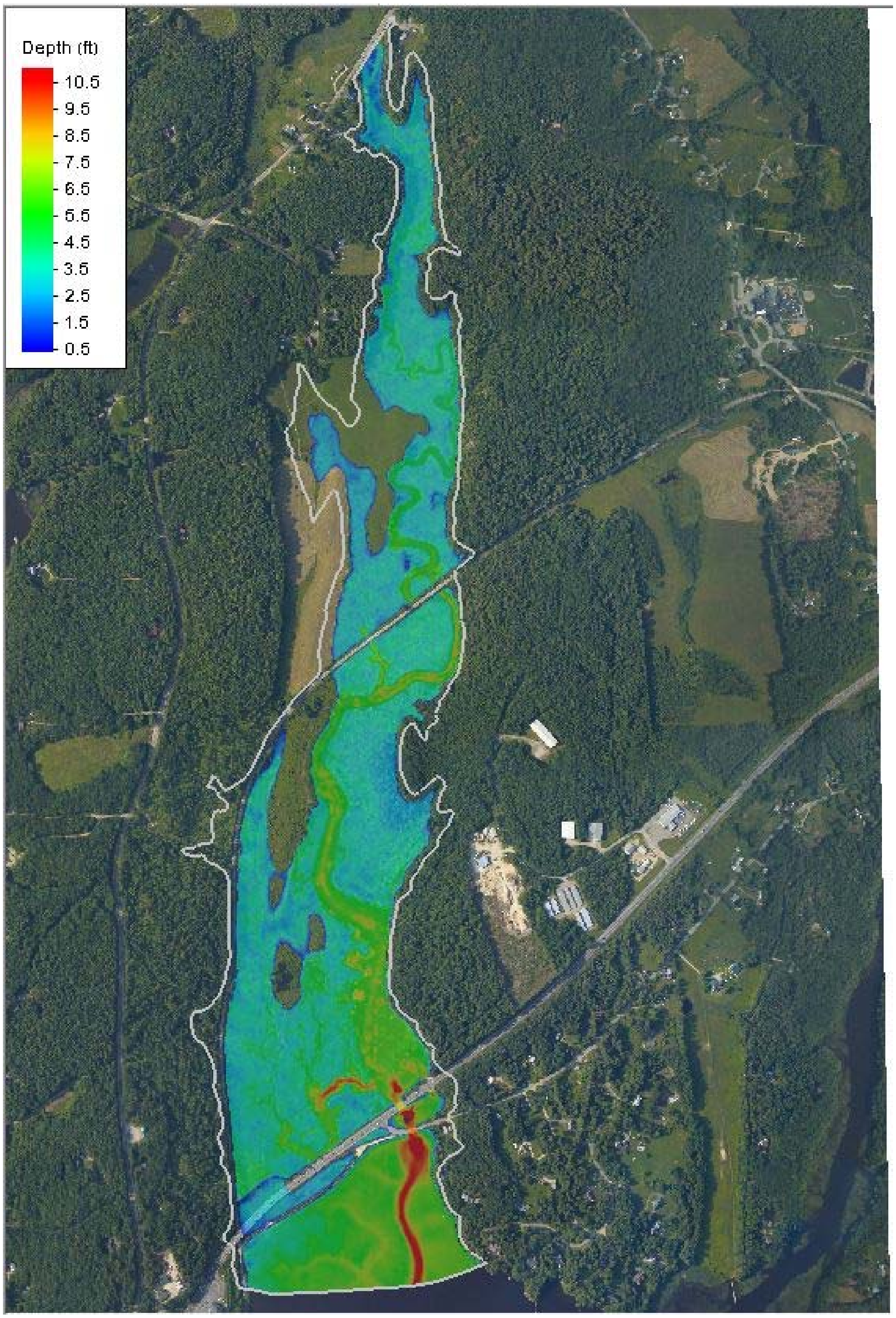

Figure A-7. Preferred Alternative 100-year return period freshwater discharge with typical tides – Maximum water depths.

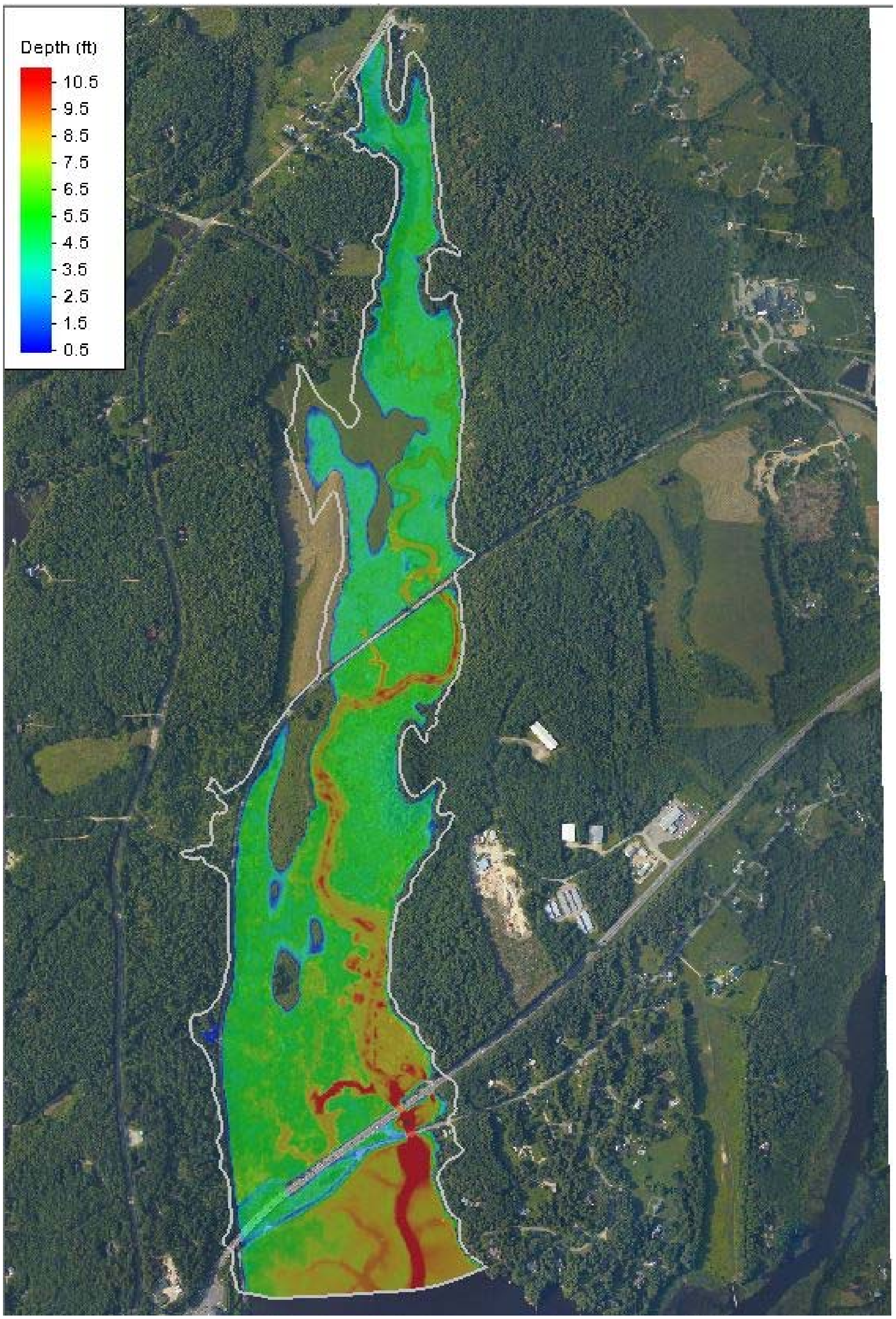

Figure A-8. **Preferred Alternative 100-year return period freshwater discharge with typical tides with 2 ft SLR – Maximum water depths.**

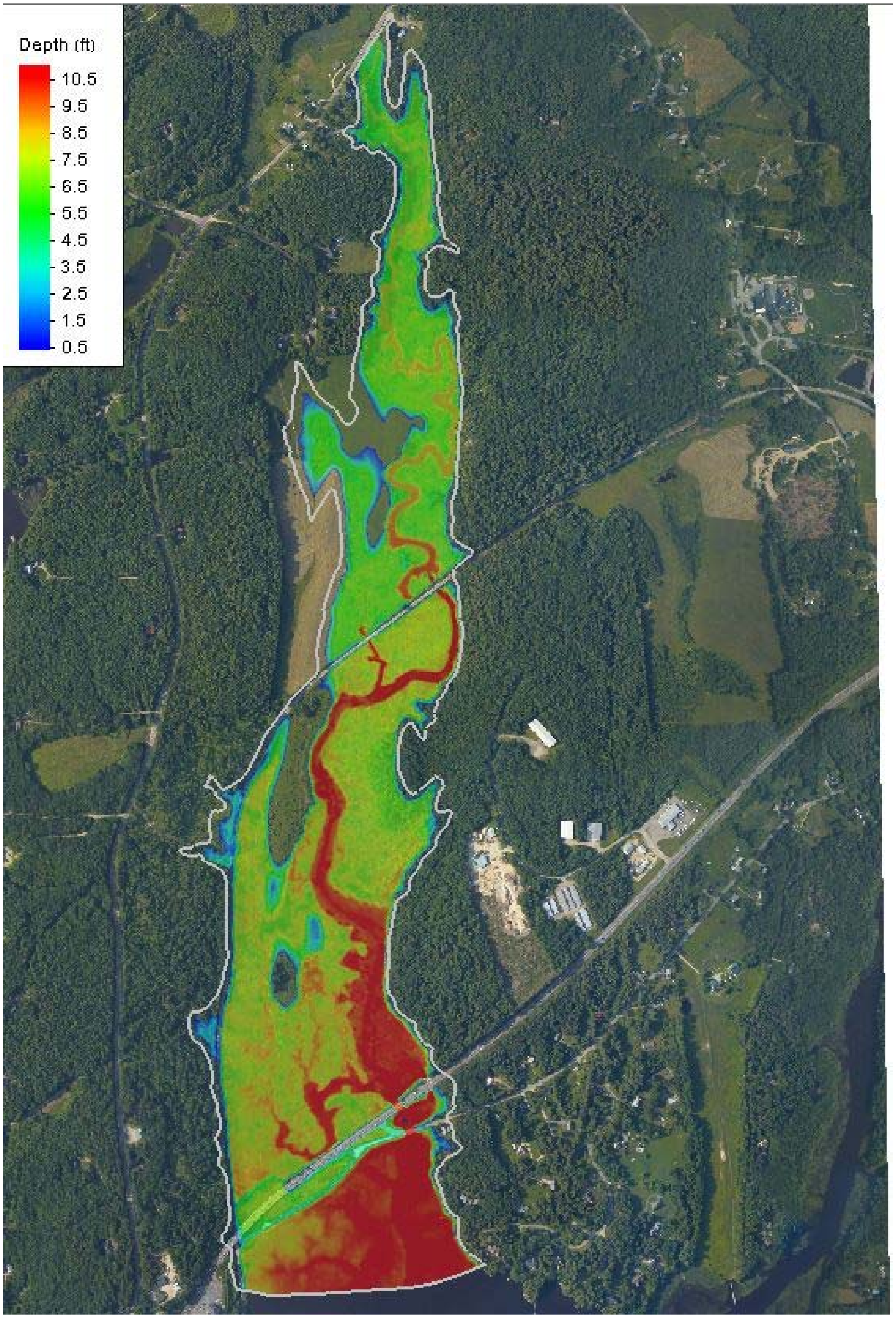

Figure A-9. **Preferred Alternative 100-year return period freshwater discharge with typical tides with 4 ft SLR – Maximum water depths.**

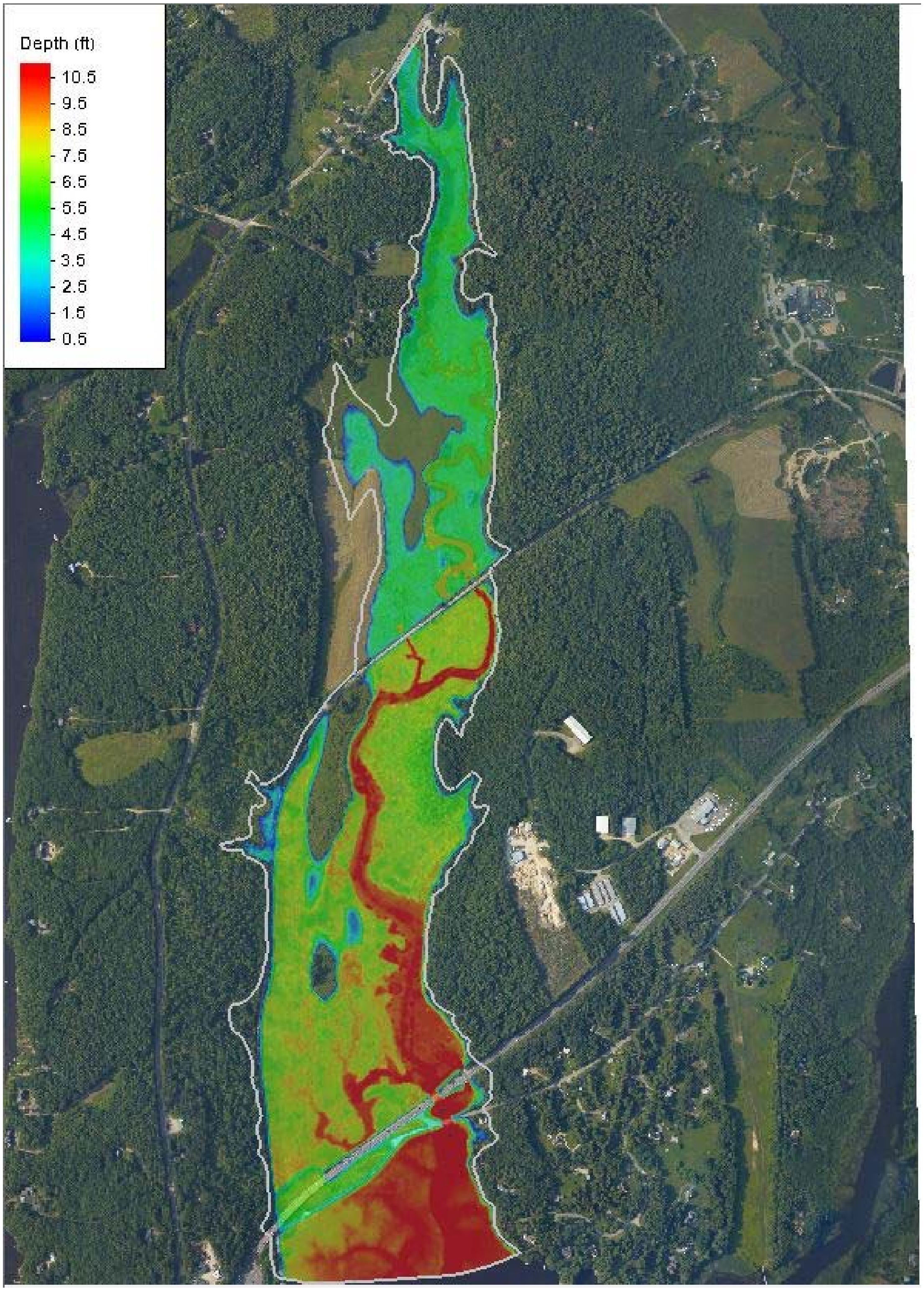

Figure A-10. **Preferred Alternative 50-year return period surge event – Maximum water depths.**

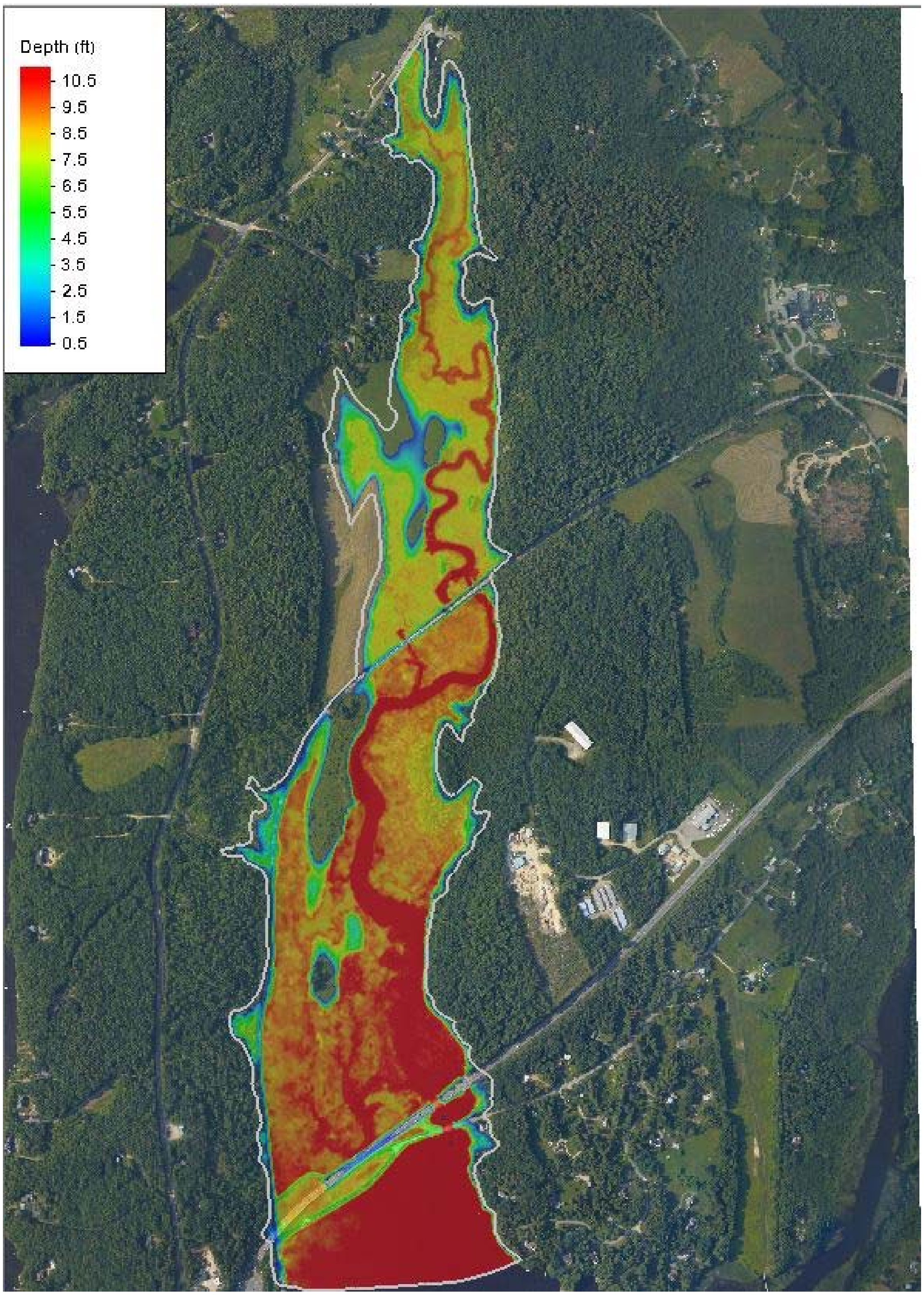

Figure A-11. Preferred Alternative 50-year return period surge event with 2 ft SLR– Maximum water depths.

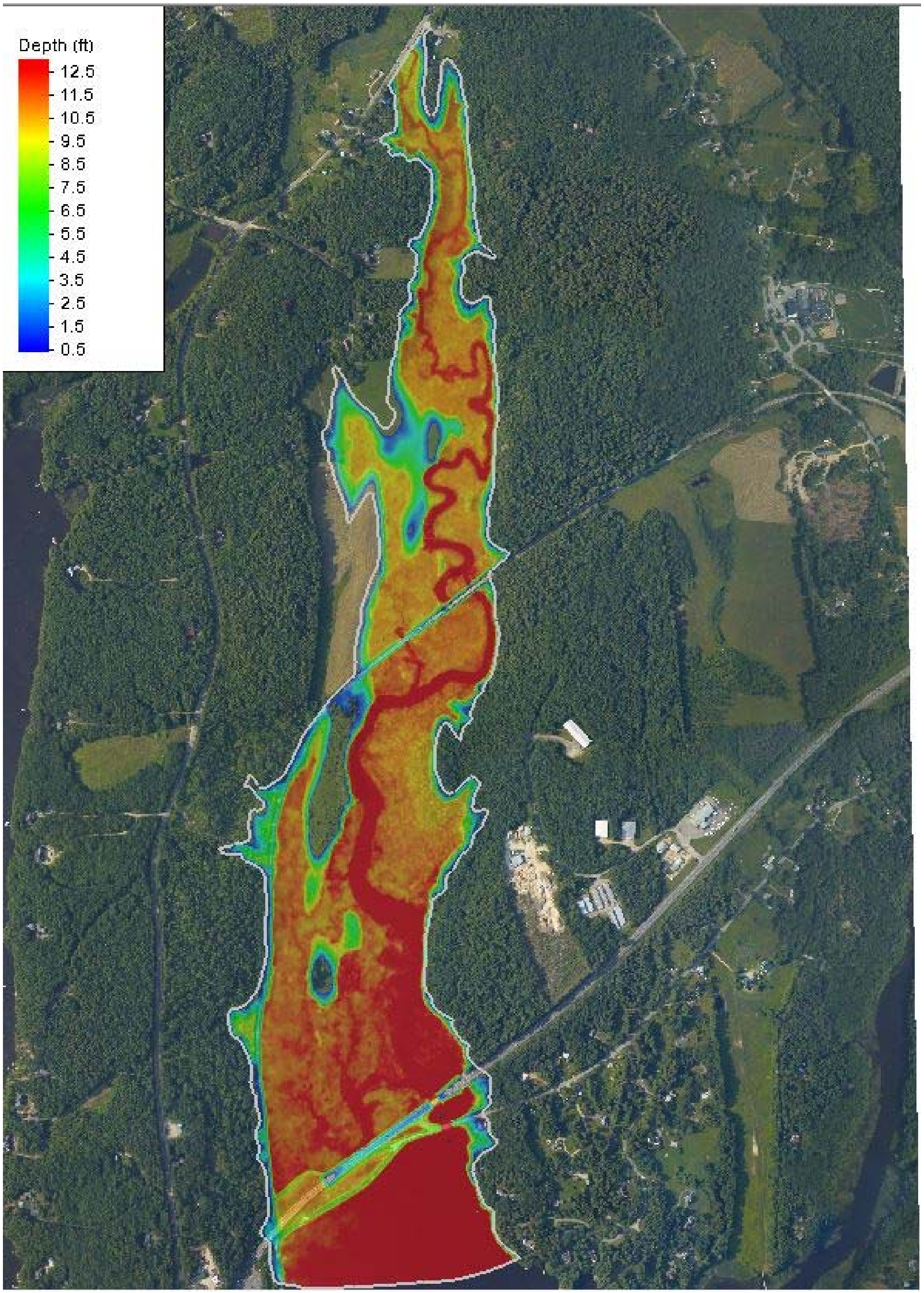

Figure A-12. Preferred Alternative 50-year return period surge event with 4 ft SLR– Maximum water depths. Scale is changed from other figures owing to maximum water depths within marsh.