Hydraulic Report

Brewer-Eddington Route 9 Connector
over
Felts Brook, Eaton Brook, and Tributaries

Federal Project No. 1891500
WIN 018915.00

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2020-11-04

Maine Department of Transportation
Bridge Program

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Project Summary

The new Route 9 will connect I-395 where it intersects Route 1A in Brewer with Route 9 in Eddington. The new roadway includes four stream crossing structures in addition to several more minor drainage structures. Three main drainage basins are included in the project: Felts Brook with its tributaries, Eaton Brook, and an unnamed tributary of Eaton Brook that joins the main stream well outside of the project limits. Each drainage basin was modeled separately and is summarized in its own report.

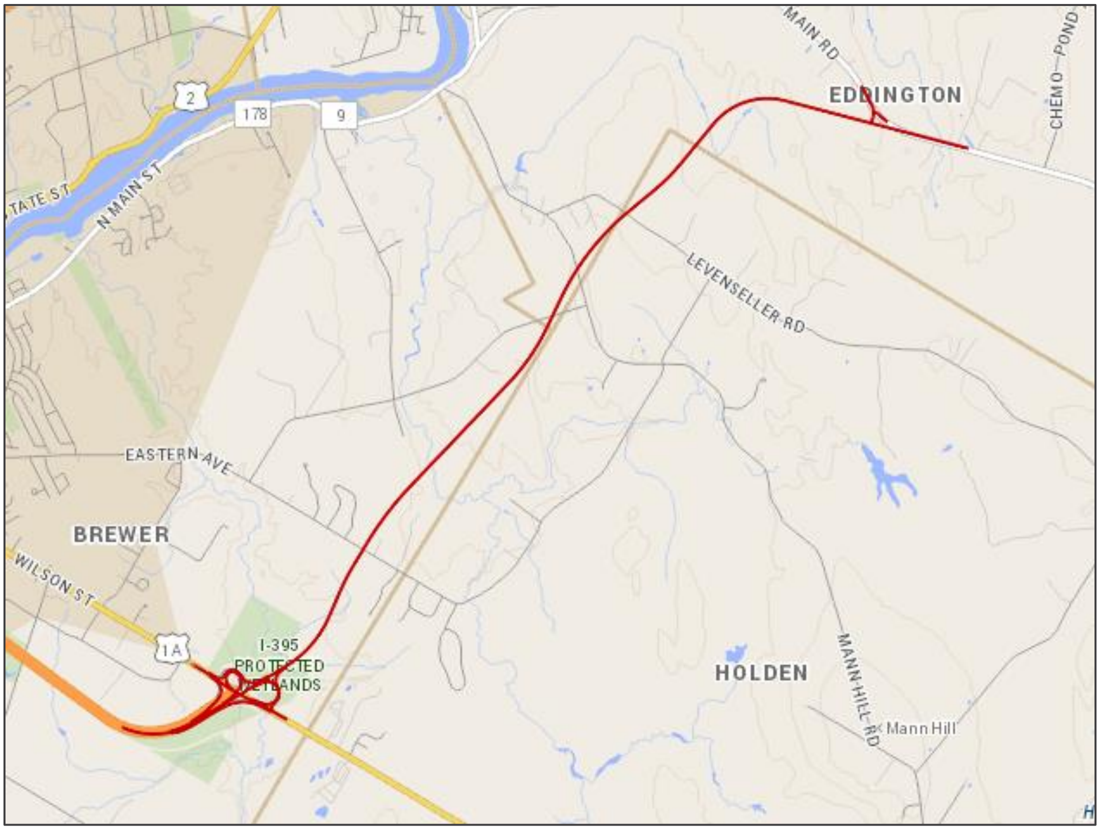

Figure 1: Overall Project Alignment

Modeling Methodology

The hydraulic models were built using the software SMS (version 13.0.8) developed by Aquaveo and used the SRH-2D analysis engine developed by the U.S. Bureau of Reclamation.

Models were built using a combination of traditional ground survey, aerial survey, and statewide LiDAR models. The survey data collected by MaineDOT for this project was primarily photogrammetric aerial survey supplemented by ground point collection at areas of specific interest, which included all stream crossings. MaineDOT survey data was collected using the State Plane coordinate system ME2000 Central Zone using US Survey Feet as the units. Where the limits of the DOT survey were not sufficient for the hydraulic model, additional data was incorporated from the Maine Office of GIS flown LiDAR library, which is collected in UTM Zone 19 with units of meters. Both the survey and LiDAR use NAVD 88 as the vertical datum.

Design Criteria

Because of the scope and special status of this project as new construction in a sensitive area, stricter hydraulic design criteria are used for this project than the standard criteria in the MaineDOT Bridge Design Guide. These criteria come in four parts:

1. The Q1.1 elevation, flooding extent, and velocity shall approximately match existing. This verifies that the 1.2BFW design is performing as intended.
2. The headwater elevation increase shall be less than 1 foot for Q100 flow with no significant changes to the flooding extent. This avoids property impacts and ensures the FEMA floodplain map does not need to be revised.
3. Q100 flow velocities shall increase less than 5 feet per second. This checks the scour conditions to make sure no major stream changes occur.
4. The head water to depth ratio (Hw/D) shall be less than 0.9 for culverts and the low chord clearance greater than 2 feet for bridges at Q100 flows. This checks general structure capacity to avoid structure damage during floods.

In addition to these criteria, the Q25 and Q50 flows will also be modeled and included as part of the project information so they are available for evaluating project delays as called for under the Standard Specifications. For Felts Brook, the Q10 and Q500 flows were modelled and compared to the values from the FEMA report, but are not reported in detail here.

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Felts Brook and Tributary
Brewer, Maine

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Watershed Description

Felts Brook flows north from Brewer to the Penobscot River. The area of interest to this project starts at the culvert crossing under Route 1A and continues part way towards Eastern Ave. A small unnamed tributary flowing west from near the old rail bed and joining Felts Brook just north of the cleared area by the intersection of I-395 and Route 1A is also included. The majority of the watershed is wooded, with some low-lying marshy areas and cleared fields.

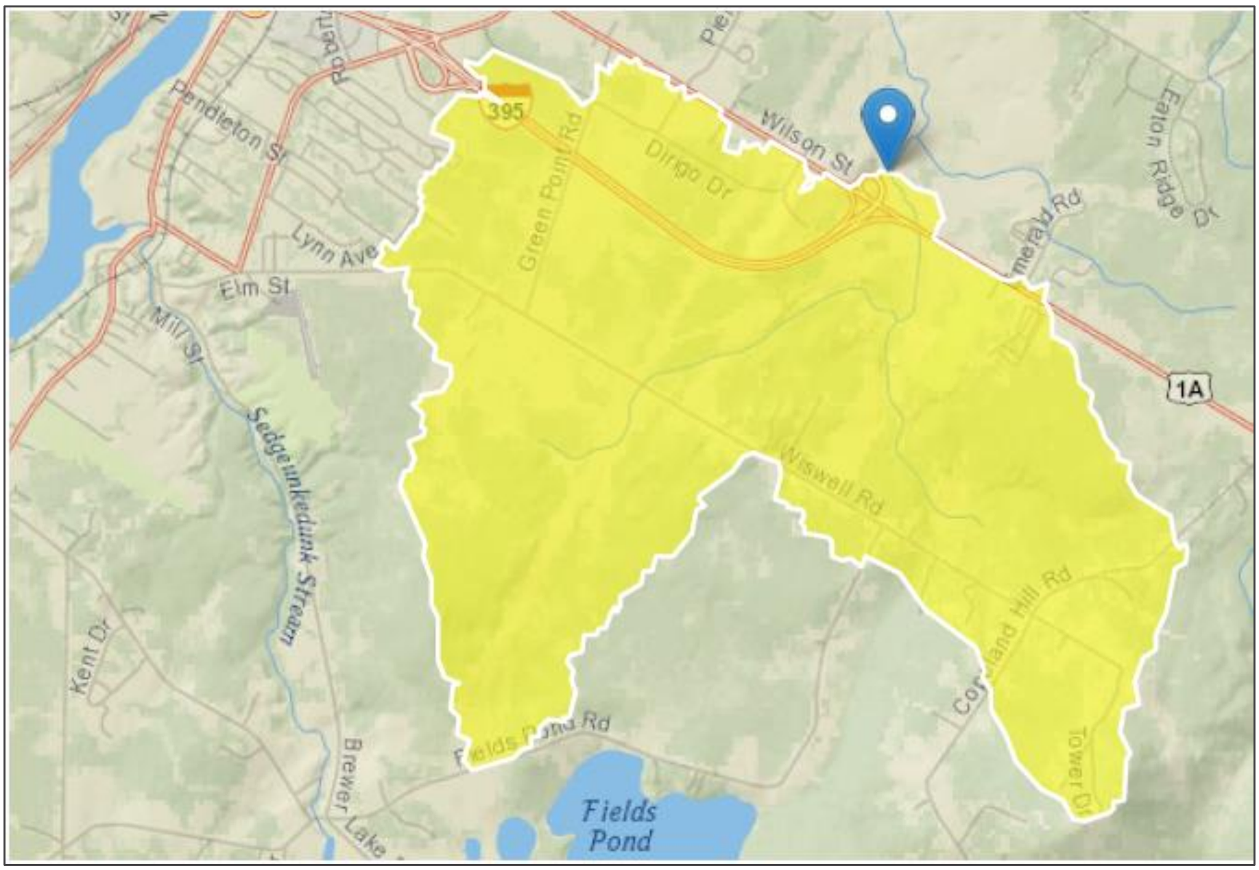

Figure 1: StreamStats watershed for Felts Brook at study site

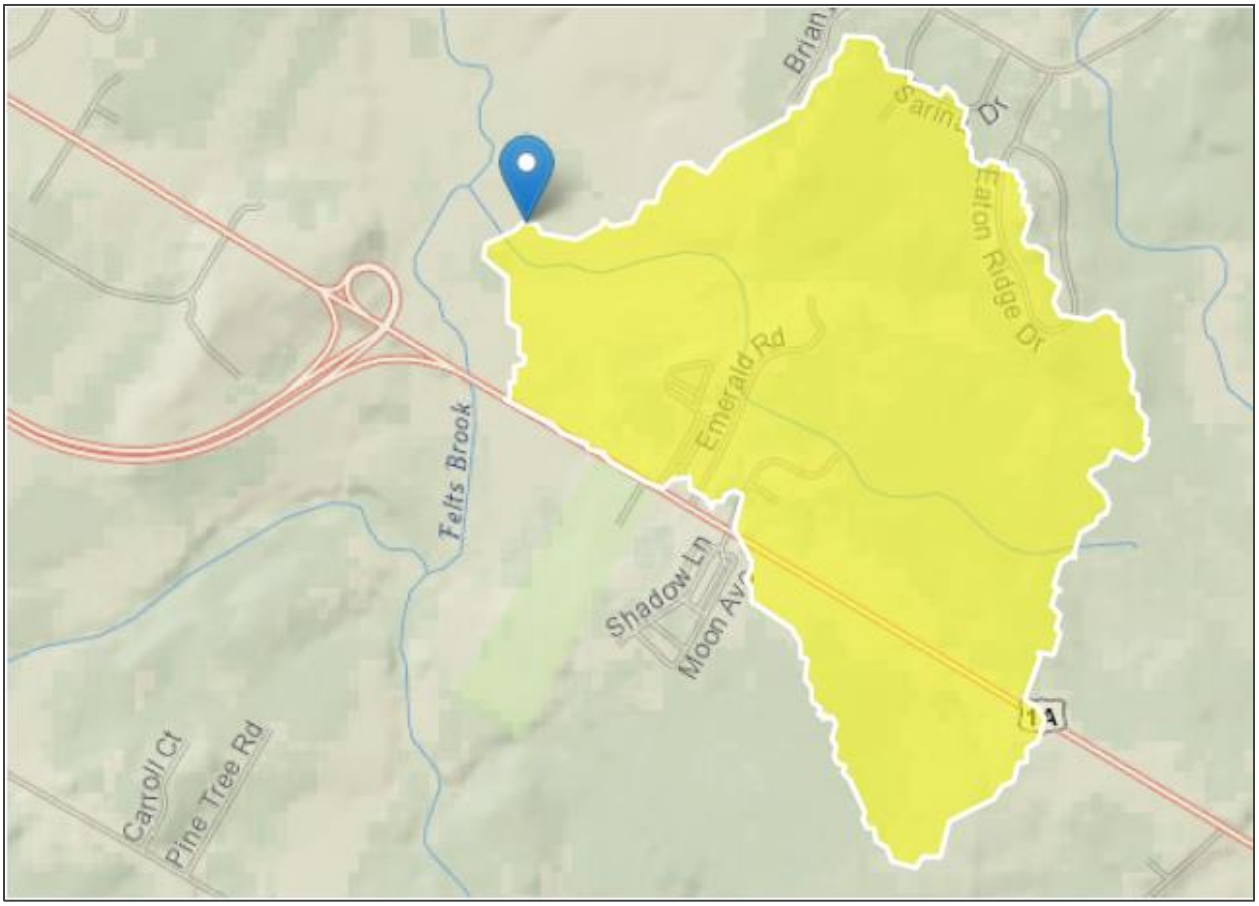

Figure 2: StreamStats watershed for tributary at study site

Nature of Flood Risk

Periodic seasonal flooding over the stream banks is typical for flatter areas of the watershed. The area of interest is well outside of the influence of the Penobscot River for flooding.

Previous Hydrologic Studies in Watershed

The FEMA Flood Insurance Study for the City of Brewer, Maine (1977) gives 1% recurrence flood flows for Felts Brook at the confluence with the Penobscot River. The Flood Insurance Rate Map for the City of Brewer (Community-Panel Number 230104 0005 B, 1978) gives additional elevation and flooding limit data for Felts Brook.

Calculated Flow Data

Current flow data at the site of the proposed Route 9 alignment was calculated by the Maine DOT Environmental Office Hydrology Section using the U.S.G.S. regression equations (Hodgkins 1999 and Lombard/Hodgkins 2015).

The flows from the 1977 Flood Insurance Study were calculated using the 1975 regression equations published by U.S.G.S for Maine. Flows for the FIS are given at the confluence with the Penobscot River.

Summary of watershed and flows

	Felts Brook	Tributary	
Drainage Area	5.30	1.00	mi^2
Q1.1	79.1	24.5	ft^3/s
Q10	319.5	100.8	ft^3/s
Q25	419.5	131.7	ft^3/s
Q50	486.7	154.1	ft^3/s
Q100	570.1	180.3	ft^3/s
Q500	764.3	243.3	ft^3/s
FIS Drainage Area	9.4		mi^2
FIS 10% Recurrence	510		ft^3/s
FIS 2% Recurrence	860		ft^3/s
FIS 1% Recurrence	1040		ft^3/s
FIS 0.2% Recurrence	1620		ft^3/s
FIRM 1% Recurrence Elevation	82.3		ft
FIRM 1% Elevation Downstream	80.5		ft

Note: FIRM elevations converted from NGVD 1929 to NAVD 1988 (datum shift of -0.702 ft).

Table 1: Summary of watershed and flows

Hydraulic Report

Introduction

This report was prepared for MaineDOT to evaluate the hydraulics of two box culverts and one overflow pipe under the new Route 9 connector where it crosses Felts Brook. Since the structures are within the same flood plain, one hydraulic model was used to evaluate the entire area. The models for both the existing condition with no roadway or structures and the proposed roadway and crossing structures are described below.

Model Development

For the main Felts Brook channel, the model extends upstream to the Route 1A culvert crossing. On the tributary, the model extends for a longer distance up into a wooded area to ensure that the inflow boundary is higher than the flooded area being studied. The downstream boundary was set in an area where the channel and surrounding topography narrowed to create a more narrowly bounded section instead of a broad flooded area. Side boundaries were trimmed to an elevation high enough to ensure that they were above the flooded area.

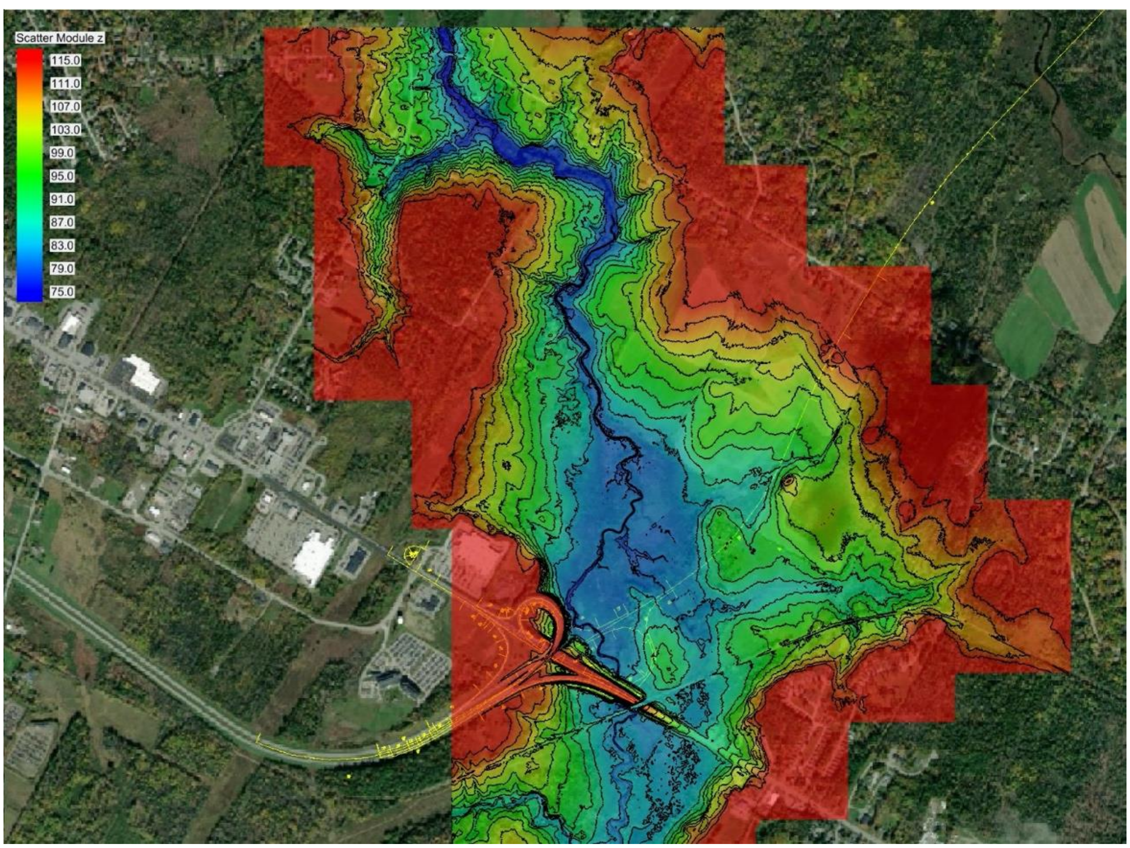

Figure 3: Existing terrain model with color filled contours overlaid on satellite photo

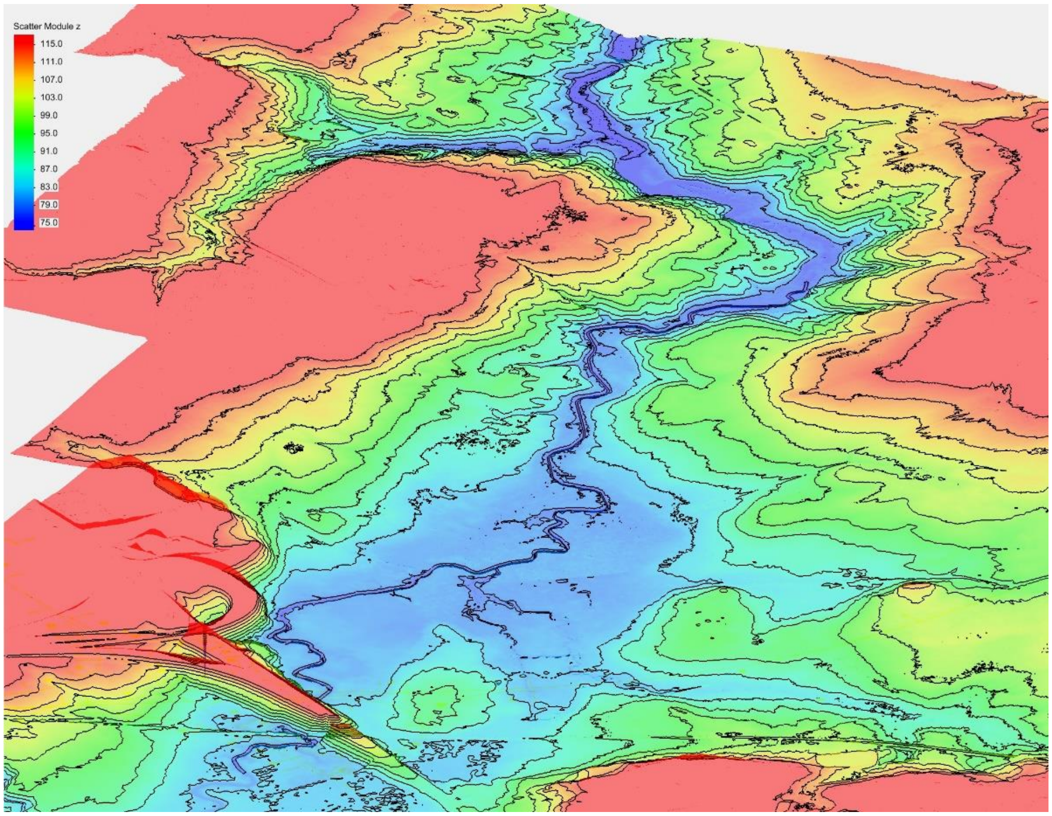

Figure 4: 3D view of existing terrain model

To develop the terrain model for the bridge, the point data of the surface created by DOT Survey for the project was combined with additional LiDAR point data from MEGIS to extend the model beyond the survey limits. Since LiDAR does not detect surfaces below water, the surface was edited to add a trapezoidal channel mimicking the general stream cross section downstream of the survey data. A short side channel to connect the tributary was also added to resolve discrepancies at the transition between the ground survey and LiDAR that were causing unrealistic results.

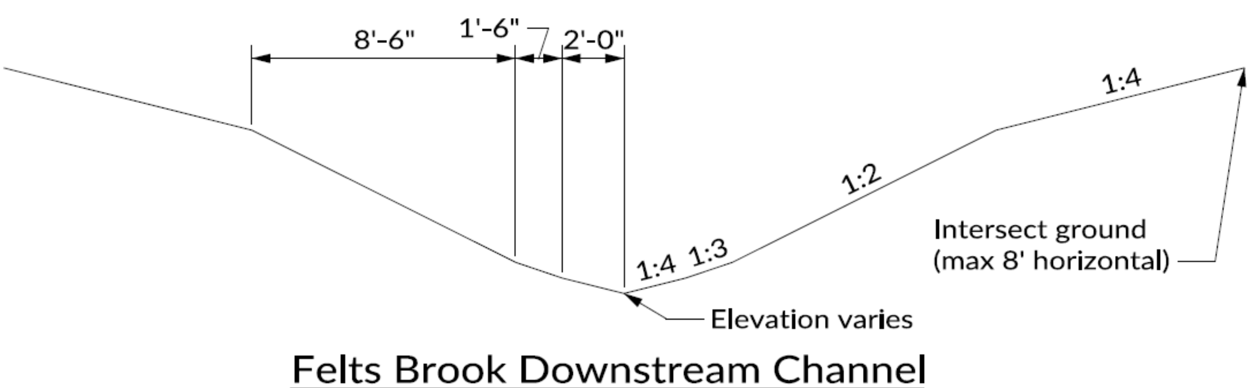

Figure 5: Stream section for artificial channel downstream for Felts Brook outside of ground survey

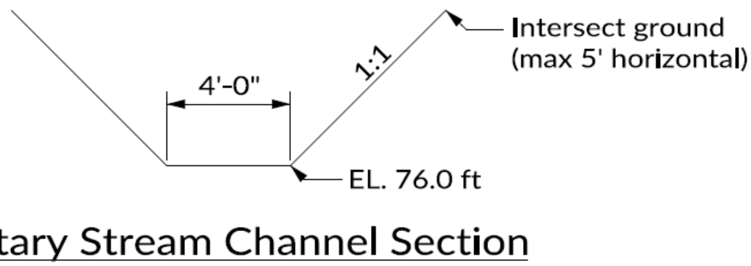

Figure 6: Stream section for artificial channel connecting Tributary to Felts Brook outside of ground survey

Figure 7: Layout of channels added to LiDAR data

The developed mesh has almost 214,000 elements covering 427 acres. The mesh density is highly variable, with spacings of 100 feet on the outside boundaries, 25 feet on intermediate lines, and 5 feet on the channel elements. This distribution was used to give results at the scale of the channel without creating a substantial number of elements in other areas of the model. When using the built-in mesh check tools in SMS, a significant number of elements are labeled as having the mesh quality issue “Maximum slope”, but this appears to be primarily due to the terrain, not an issue with the mesh creation. A dataset calculating the difference between the mesh and the underlying elevation scatter set to check that the mesh accurately reflects the ground surface shows an excellent correlation.

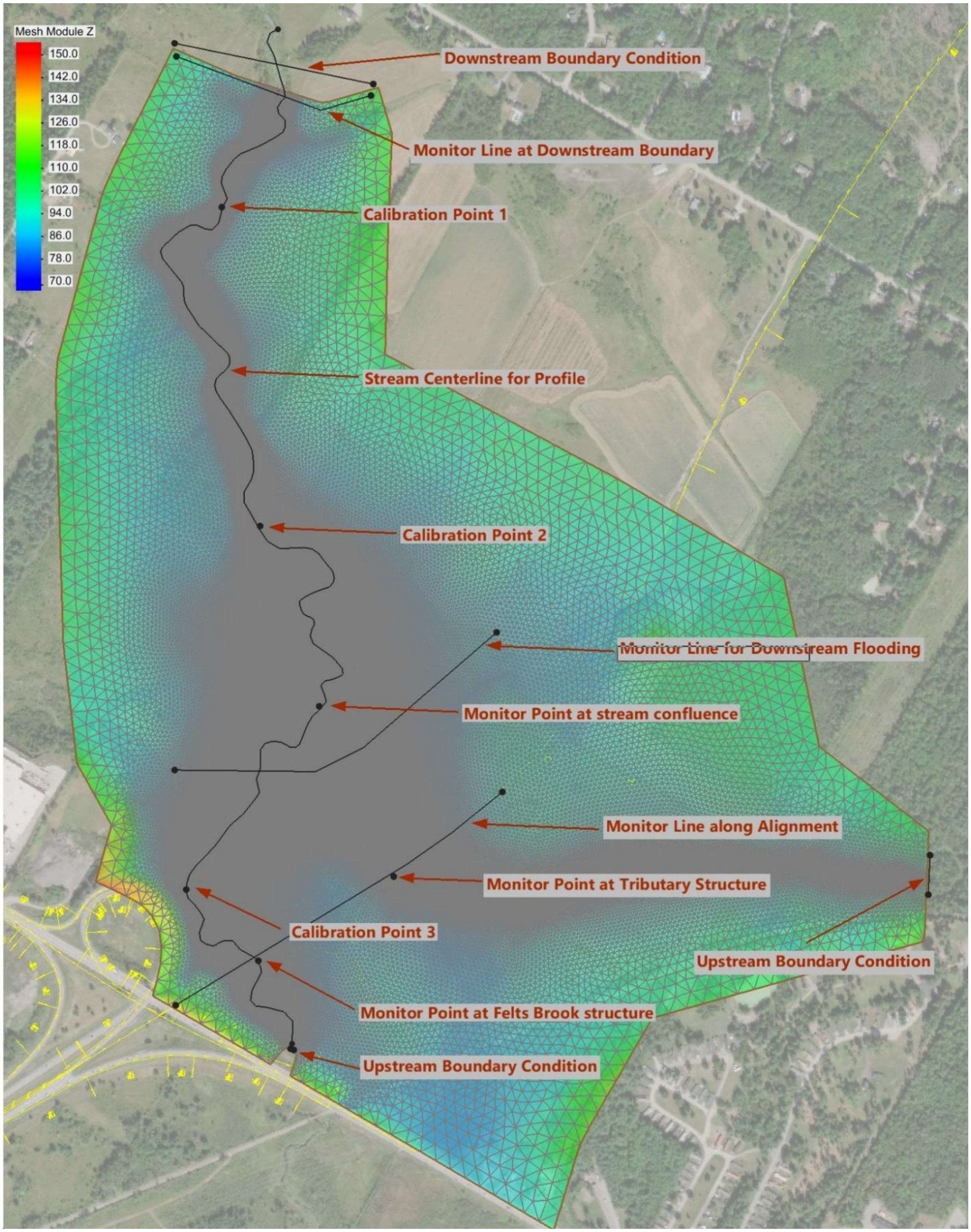

Figure 8: Mesh and coverages labelled to show calibration and monitor points where results were checked

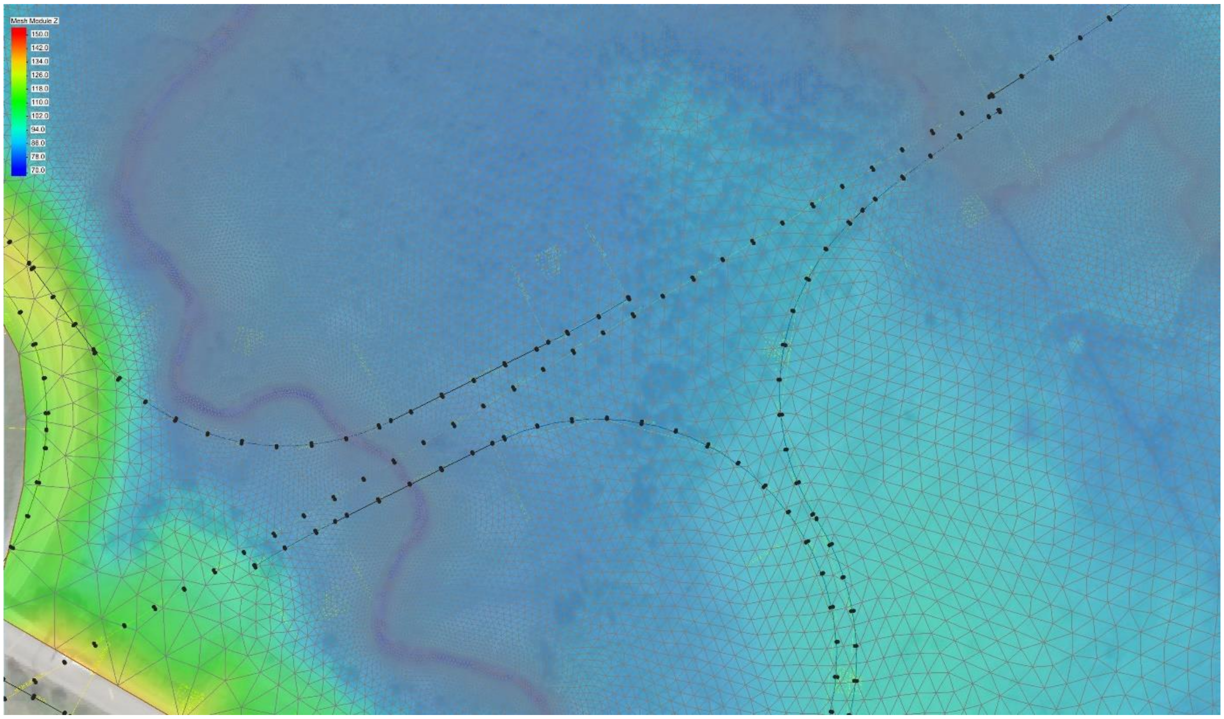

Figure 9: Detailed view of existing condition mesh at the structures with color assigned by elevation and proposed mainline and ramp alignments shown

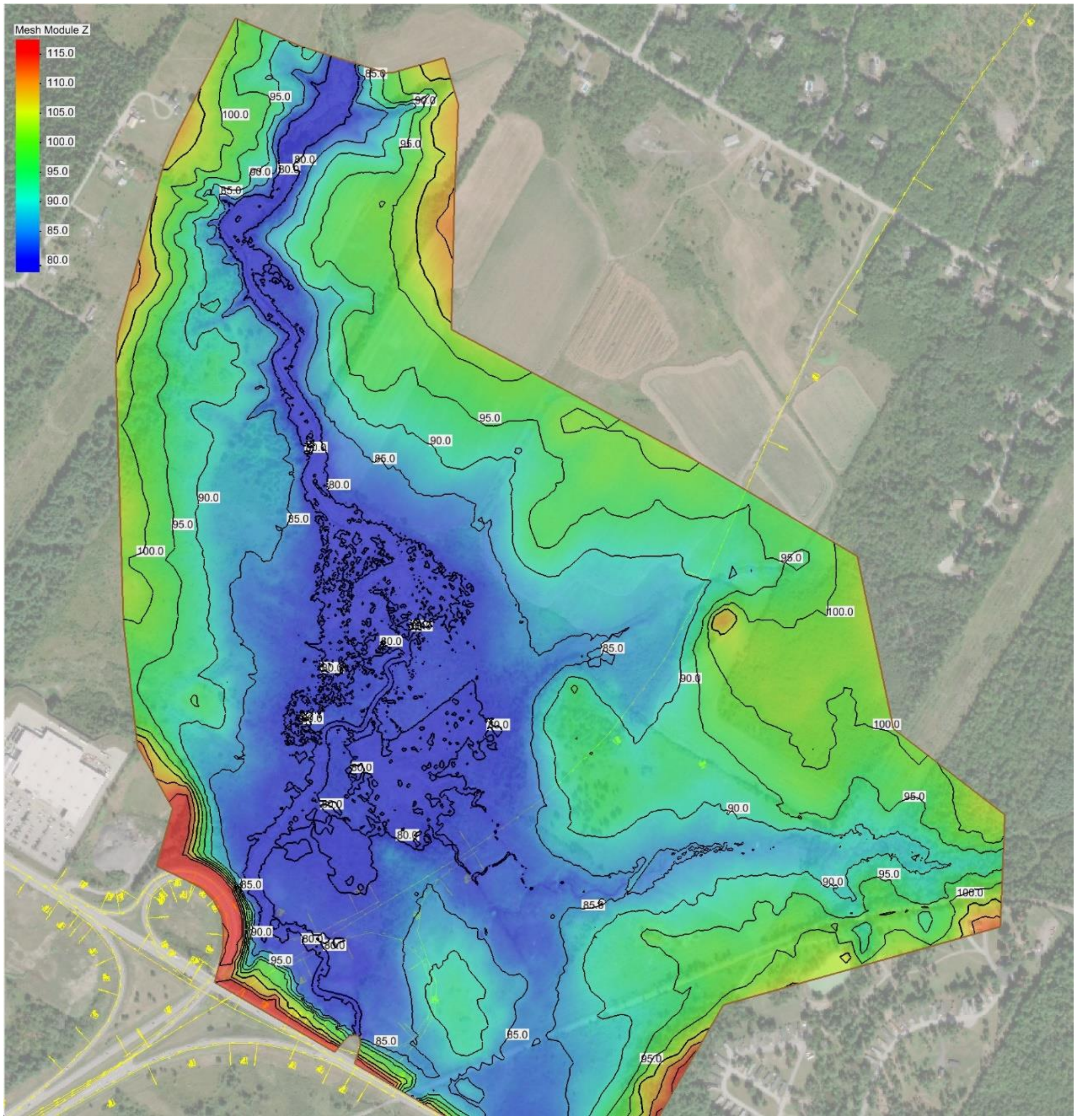

Figure 10: Mesh contours showing elevations for the existing condition

The inflow boundary conditions are Inlet-Q (defined flow) lines set at the upstream limits of the model. The flow and elevation data from the FIS will be used to calibrate the model, but the FIS flows are for the confluence with the Penobscot River and have a larger drainage area. In order to use them for comparison to the regression flows at the model site, they need to be converted to a similar drainage area. To do this, a StreamStats regression flow at the confluence was calculated, and used to determine the proportion of the flow at the Penobscot that was present at the site. The FIS flows were reduced using this proportion to create a value representative of the smaller drainage area.

The ratio between the Felts Brook and Tributary flows from the regression equations was used to split the FIS flows into the two boundary conditions. This resulted in a set of flows for the FIS results split between the two streams and based on the watershed area of the model.

Return Period	Felts Brook	Tributary	Total Regression at Proposed Alignment	StreamStats at Penobscot	FEMA at Penobscot	Difference
Area	5.3	1	6.3	9.5	9.4	0.1
1.1	79.1	24.5	103.6	80.5		
2	162.4	50.7	213.1	281		
5	255.3	79.9	335.2	446		
10	319.5	100.8	420.3	561	510	51.0
25	419.5	131.7	551.2	738		
50	486.7	154.1	640.8	862	860	2.0
100	570.2	180.3	750.5	1010	1040	-30.0
500	764.3	243.3	1007.6	1360	1620	-260.0
Calculation Formula			*Felts + Tributary*			*StreamStats – FEMA*

Table 2: FIS flow comparison

Return Period	Factor	FEMA Reduced	Stream Split	FEMA Felts	FEMA Trib
Area	0.66		0.19		
1.1	1.29	1.01 return period in Stream Stats			
2	0.76		0.31		
5	0.75		0.31		
10	0.75	382	0.32	262	121
25	0.75		0.31		
50	0.74	639	0.32	437	202
100	0.74	773	0.32	528	244
500	0.74	1200	0.32	818	382
Calculation Formula	*Total / StreamStats*	*FEMA * Factor*	*Tributary / Felts*	*(1 - Split) * Reduced*	*Split * Reduced*

Table 3: FIS flow adjustment calculations

The exit boundaries is an Exit-H (set elevation) lines For the FIS flows, the downstream water elevation was estimated from the profile for Felts Brook (sheet 06P in the FIS report) approximately 6500 feet downstream from Route 1A. The FIS flows were also used to calibrate an approximate stream slope of 0.0006 ft/ft and downstream composite roughness values ranging from 0.027 for Q10 flow to 0.057 for Q100. These values were then used in the boundary condition tools in the SMS software to estimate downstream water elevations for the regression flows. To evaluate whether the model was sensitive to changes in the downstream boundary condition, the Q100 flow was run with the downstream boundary elevation varied by ±0.5 feet. The change in water elevation at the proposed structure locations was about 1 inch in magnitude, so the model is not very sensitive to changes in the downstream boundary condition.

The model uses a Manning's n in the channel of 0.04, 0.12 for forested areas, 0.06 for scrub and brush, and 0.035 for grass floodplain or field. The model's sensitivity to changes in the roughness was tested by running the Q100 flow multiple times with a single roughness value adjusted up or down by 0.01 each time. All changes to water elevations were less than 1 inch in magnitude at the proposed structure locations, so the model is not sensitive to changes in roughness.

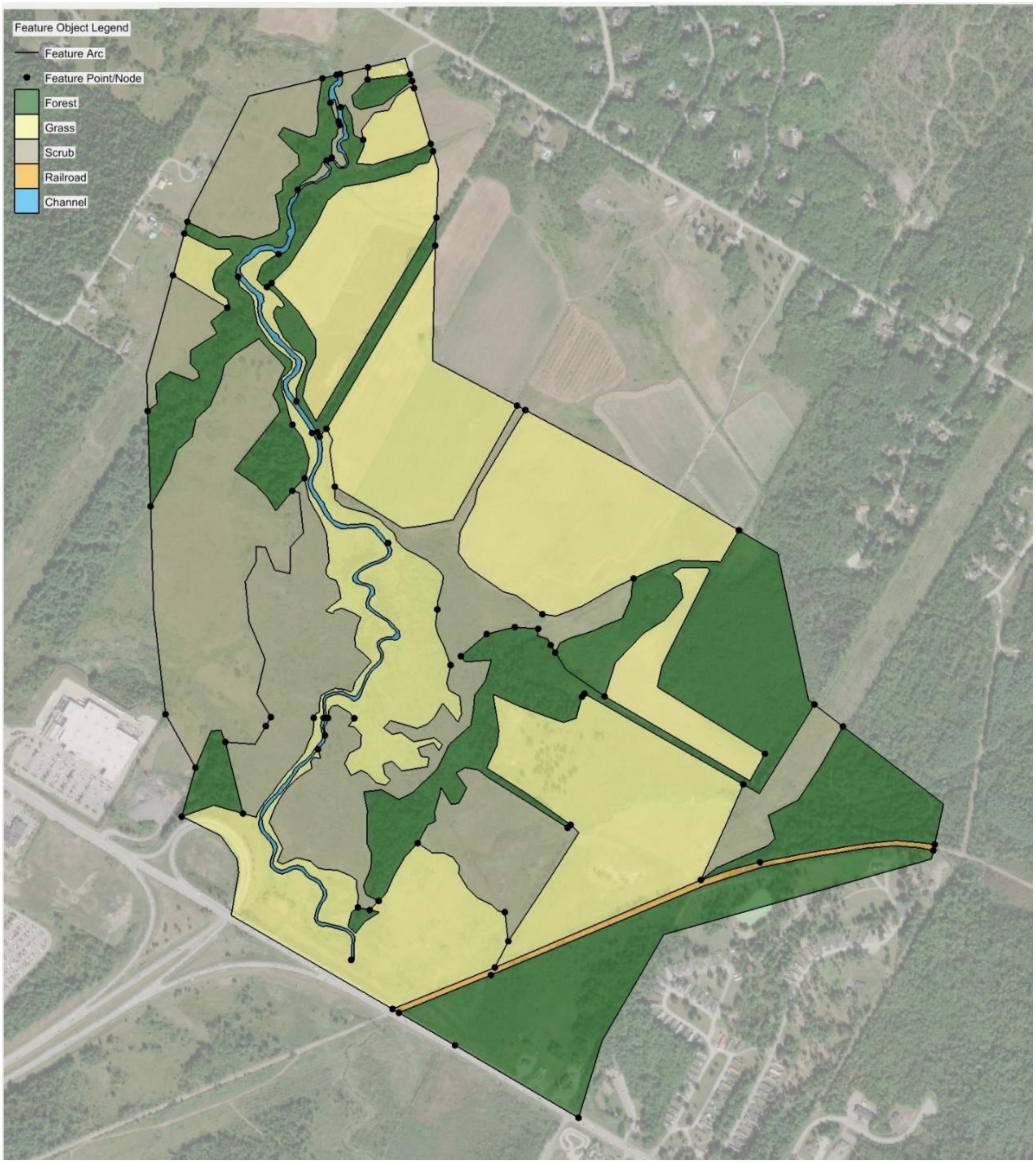

Figure 11: Layout of roughness assignments over the entire model

Figure 12: Roughness assignments at the structures for the existing condition

The only data available for calibration was the FIS model. Since this is another much older hydraulic model, not observed flood elevations, it was not used for exact calibration, but still provides a useful comparison to make sure the model elevations are making sense. The locations where whole number elevation contours on the FIRM crossed the stream were added to an Observation coverage in SMS as points and assigned the FIRM flood elevations converted to NAVD 88. This yielded a set of three calibration points for each of the FIS flows, with elevations interpreted from the profile on sheet 06P of the report.

While using the FIS profile to determine downstream boundary and calibration elevations, an apparent discrepancy was identified between the location where the 1% recurrence water elevation crosses the 81 ft elevation on the FIS profile and where the contour line is drawn on the FIRM. The horizontal distance between the two is approximately 1000 feet. A small discrepancy was also identified at the 83 foot contour, but at about 200 feet, that measurement is close to the accuracy of the scaling methods used to measure the difference. The location of the 81 ft contour on the FIRM was used as an observation point, but with elevations assigned according to the FIS profile for consistency with the other points.

Point	***x***	***y***	***Target Elevation***	***Error Bar Interval***	***Computed Elevation***	***Elevation Difference***
10%						
Felts 1	1745611	468147.1	78.0	1	79.82	1.82
Felts 2	1745828	466350.6	78.6	1	81.22	2.62
Felts 3	1745411	464302.7	79.6	1	81.44	1.84
2%						
Felts 1	1745611	468147.1	79.6	1	80.70	1.10
Felts 2	1745828	466350.6	80.3	1	82.14	1.84
Felts 3	1745411	464302.7	81.3	1	82.25	0.95
1%						
Felts 1	1745611	468147.1	80.5	1	81.24	0.74
Felts 2	1745828	466350.6	81.3	1	82.58	1.28
Felts 3	1745411	464302.7	82.3	1	82.67	0.37
0.2%						
Felts 1	1745611	468147.1	82.7	1	82.98	0.28
Felts 2	1745828	466350.6	83.3	1	83.99	0.69
Felts 3	1745411	464302.7	84.3	1	84.05	-0.25

Table 4: Results for calibration to FIS profile elevations (all elevations in feet NAVD)

As is obvious from the chart of observation data, the model has much smaller discrepancies for high flows than lower ones and the biggest difference is at Point 2. The larger discrepancy at Point 2 is almost certainly due to differences between the two models in how the profile is drawn. Since the FIS model used widely spaced cross sections, the ground elevation at any given point not on a cross section is interpolated. At the location of Point 2, the ground elevation in the 2D model is 2-3 feet higher than the elevation interpolated from the FIS profile, so the water elevation being higher as well makes sense.

The discrepancy at lower flows is harder to explain. Since the model sensitivity testing showed the model was stable relative to roughness and downstream boundary conditions, it seems likely that the discrepancy is due to differences in the topographic data used, but without detailed information from the FIS model it is impossible to say for sure. Since the results have a reasonable discrepancy at the design flood flows, the comparison to the FIS is enough to validate the general accuracy of the model and that it is suitable for design.

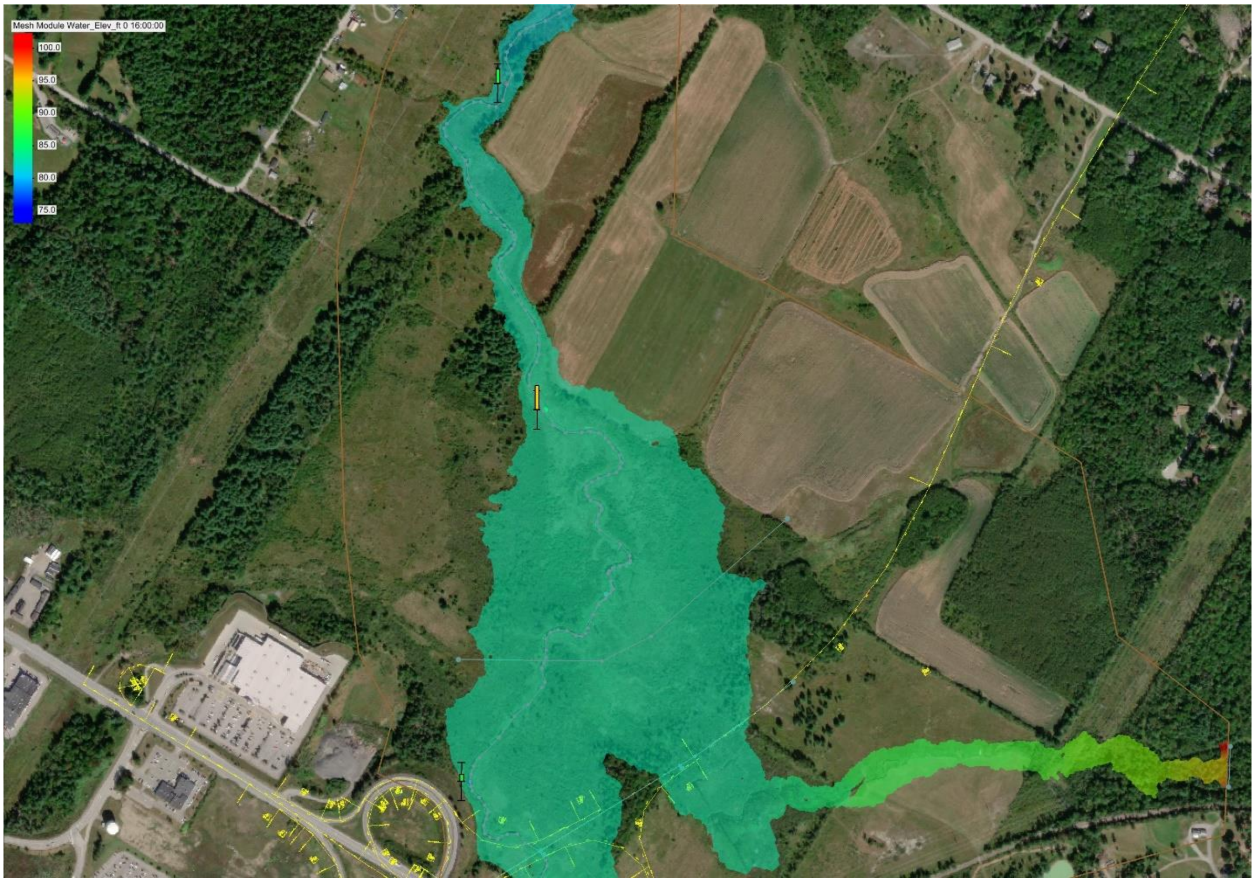

Figure 13: Calibration targets for 1% FIS elevations with 1 ft error bars

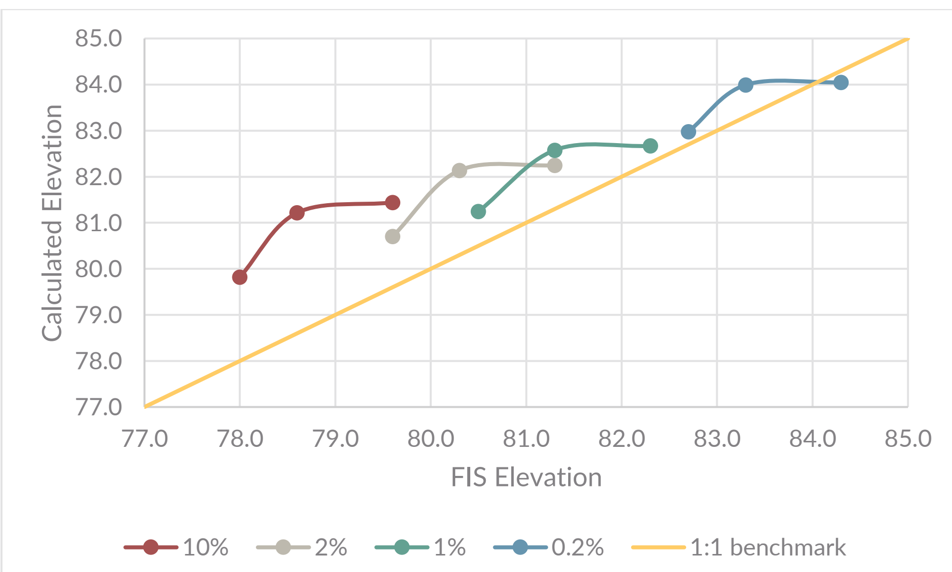

Figure 14: Graph of computed vs. FIS elevations

The calibration model runs used a time step of 5 seconds and started at a run time of 16 hours with a dry initial condition. Once enough information was available to justify it, the initial condition was changed to a water elevation of 81 feet to reduce the time required to fill the model, and the run time was reduced to 8 hours. Results were output at a frequency of 30 minutes.

To check whether the run time was sufficient, the flows through the monitor lines were checked to see how closely the values converged. For lower flows, the 8 hour run time did not achieve the convergence desired, so for the final model analysis, the run time was increased to 12 hours with the same 30 minute output frequency. Final model runs were done with the initial condition set to automatic to allow SMS to determine what the best option was.

Once the existing model had been calibrated, the 3D highway design model was converted to a set of point elevations and then merged with the existing point data in SMS. Surfaces representing the culverts' streambed section for both Felts Brook and its tributary and the stream realignment at Felts Brook were created using CAD and converted to point elevations as well. An 8′ RCP overflow culvert was created as a simple stamped surface within SMS. The final merged set created from the existing survey, highway model, and culvert surfaces was used to create the new proposed mesh.

The mesh definition was adjusted from the existing model by adding lines along the roadway embankment, redefining the stream channel in areas where the stream was realigned, and creating rectangular mesh elements through the culverts. These changes were to ensure the mesh would transition smoothly at those points and accurately represent elevations. The material roughness assignments were adjusted to represent the cleared area along the roadway, and the roadway embankment was assigned a roughness of 0.03.

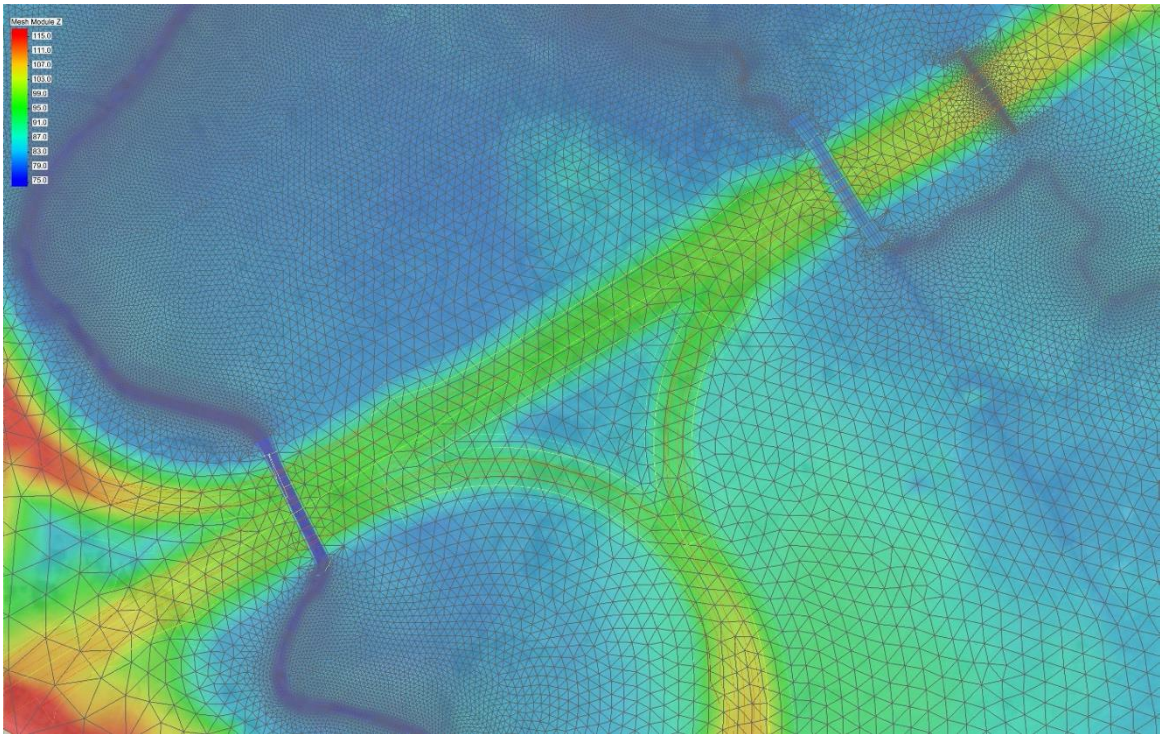

Figure 15: Detailed view of mesh at the culverts for the proposed design condition with color assigned by elevation

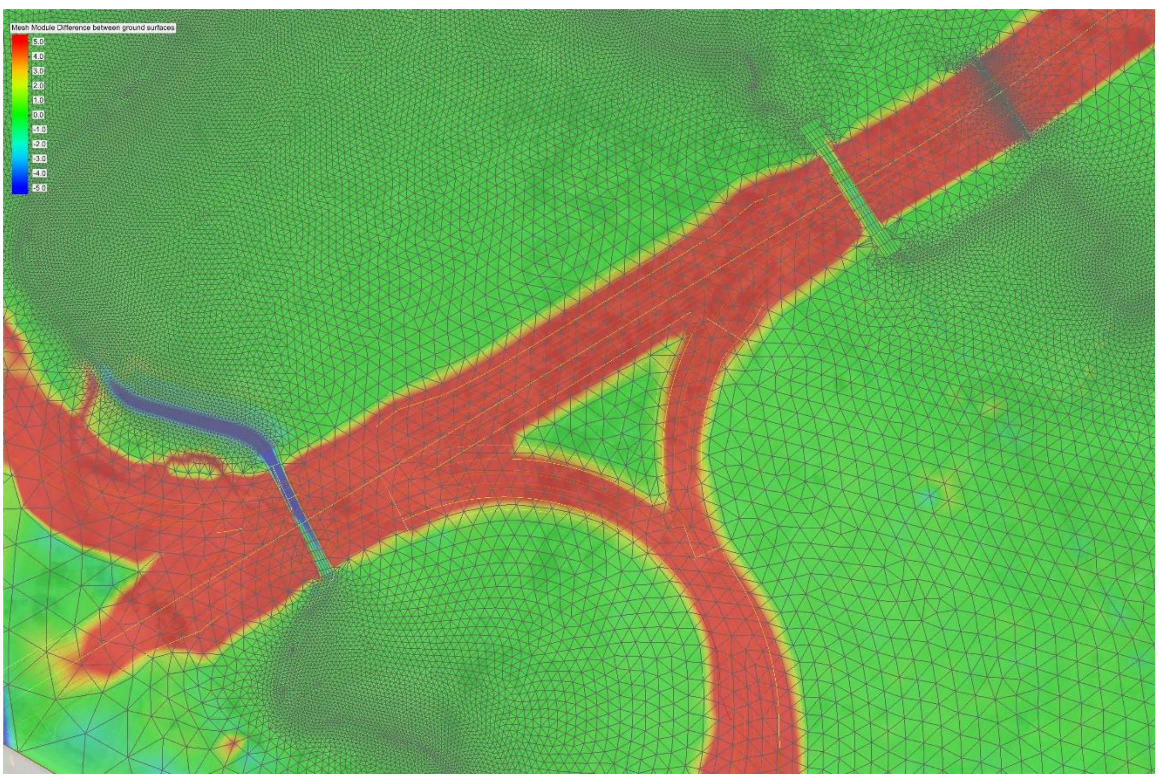

Figure 16: Difference in elevation between existing and proposed conditions highlighting new roadway embankment in red and new stream channel in blue

Figure 17: Detailed view of revised material roughness layout at culverts for the proposed condition

Addendum On Updated Survey Information

After this report was originally written, a discrepancy was discovered with some photogrammetric survey data being higher than actual in areas with tall grass. Those areas were resurveyed in January 2020. These changes only affected the Felts Brook channel, not the Tributary. An updated mesh was created for the existing model, and the Q1.1, Q10, Q25, Q50, Q100, and Q500 flows were rerun with the updated mesh so the results could be compared to the previous mesh.

- For Q1.1, Q50, Q100, and Q500, changes to elevations were less than 0.03 feet and changes to flooded area were minimal.
- For the Q10 and Q25 flows, there was a measurable change in flooded area, due to the new lower survey elevations allowing more flow across the floodplain.
- The largest change in elevation at the structure location was approximately 0.1 feet for the Q10 flow. A slightly smaller effect was present for the Q25 flow.
- Velocities decreased and changes were less than 0.4 feet per second for all flows.

Based on these results, changes are minimal at the design flows and well within the accuracy of the model. The calibration procedure was not repeated with the updated ground elevations, since the changes were too minor to affect the calibration results, but the mesh and results were updated for both the existing and proposed models to more accurately reflect the flooded areas and floodplain flow, especially at Q10 and Q25.

Hydraulic Analysis Results for Existing Conditions

The model results for the Q1.1 and Q100 flows are shown graphically here. Detailed elevations and velocities are in the summary table at the end of the report.

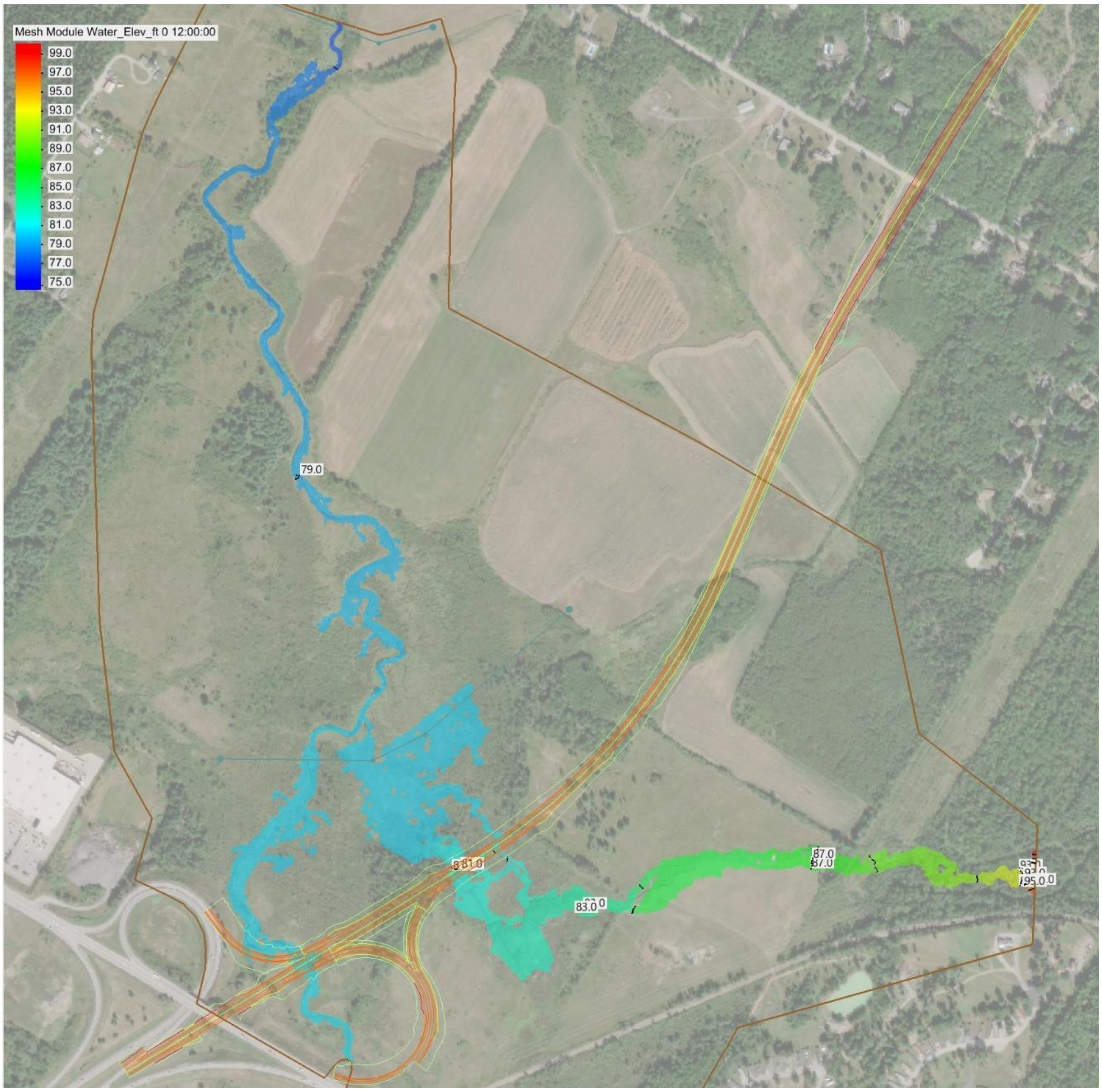

Figure 18: Existing Q1.1 Water Surface Elevation contours

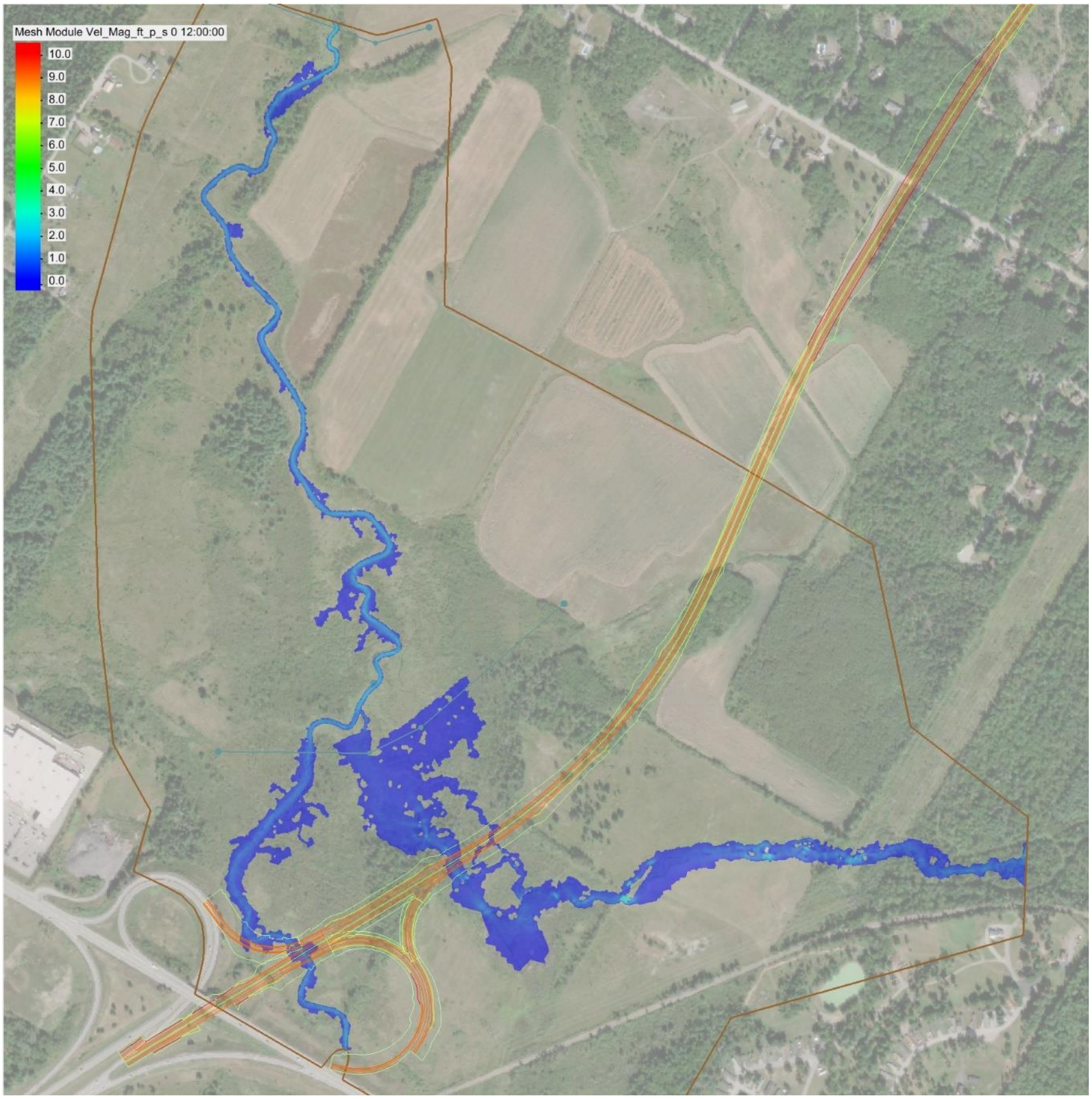

Figure 19: Existing Q1.1 Velocity contours

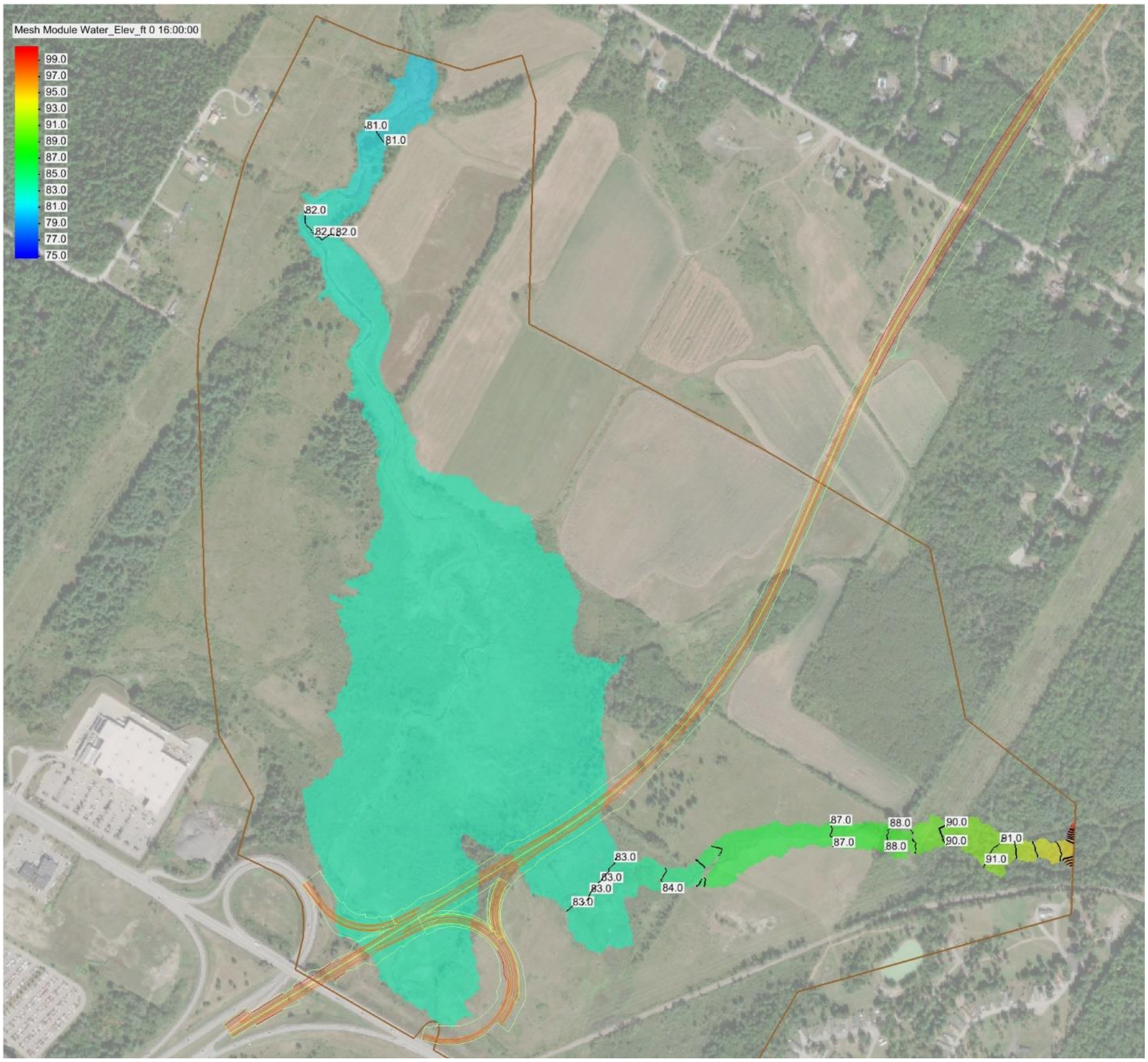

Figure 20: Existing Q100 Water Surface Elevation contours

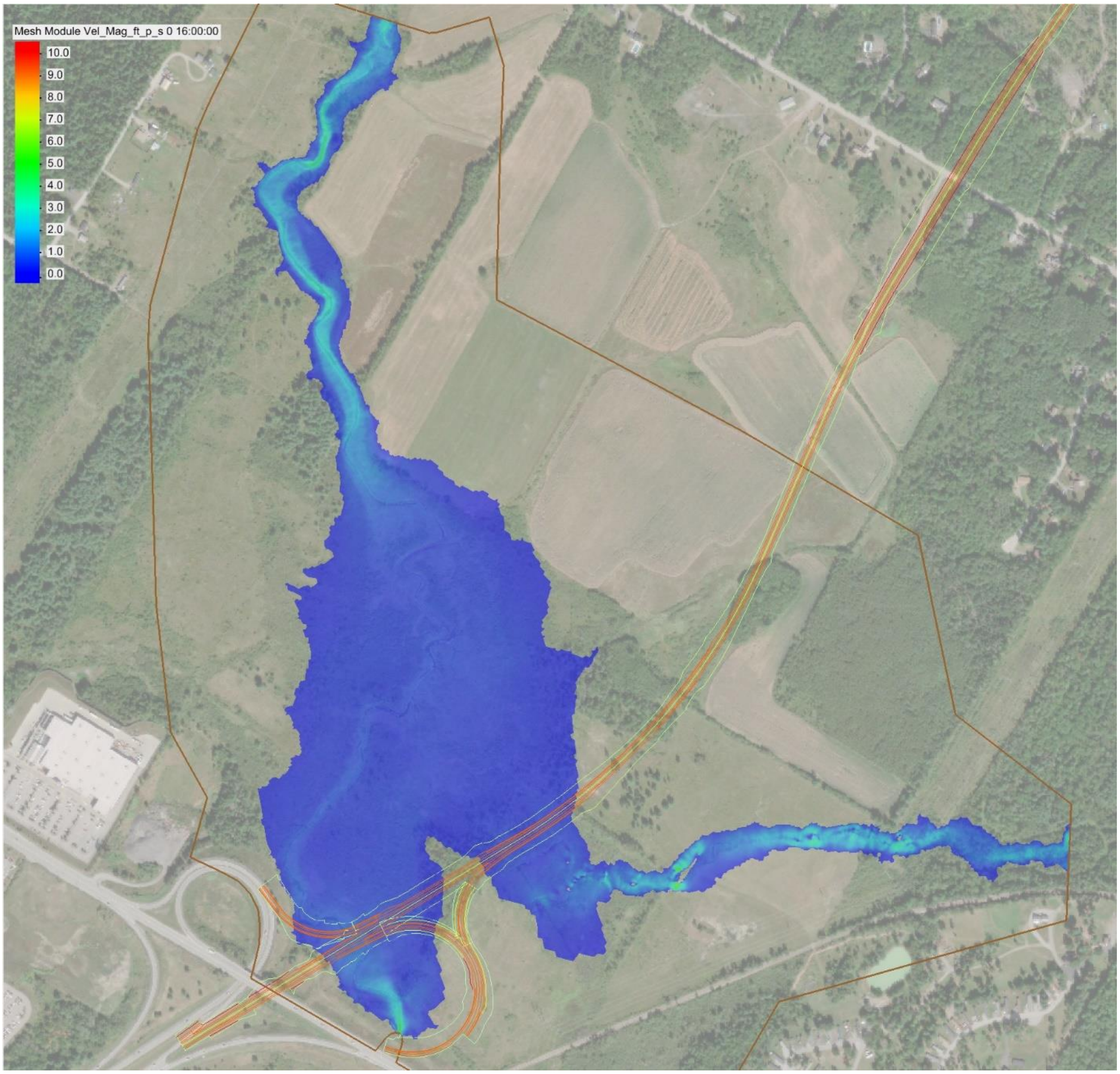

Figure 21: Existing Q100 Velocity contours

Hydraulic Analysis Results for Proposed Conditions

For the proposed condition, the primary results reported are the comparison to the existing model. Images are shown for Q1.1 and Q100 comparisons, where green values are essentially the same as existing, blue areas are where the proposed model blocked off flow, and red areas are additional areas flooded by the proposed model.

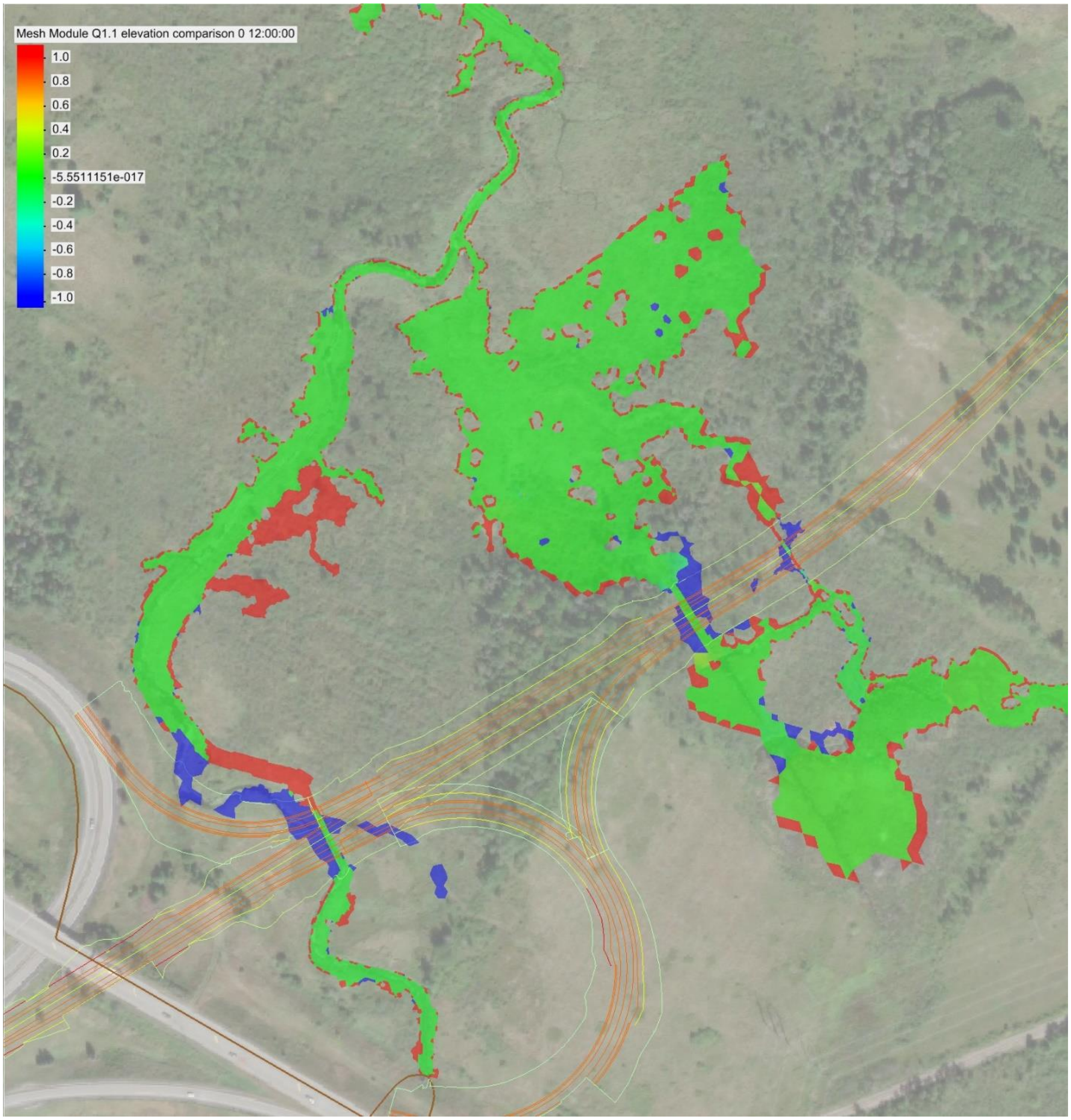

Figure 22: Q1.1 Change in Water Surface Elevations from Existing to Proposed

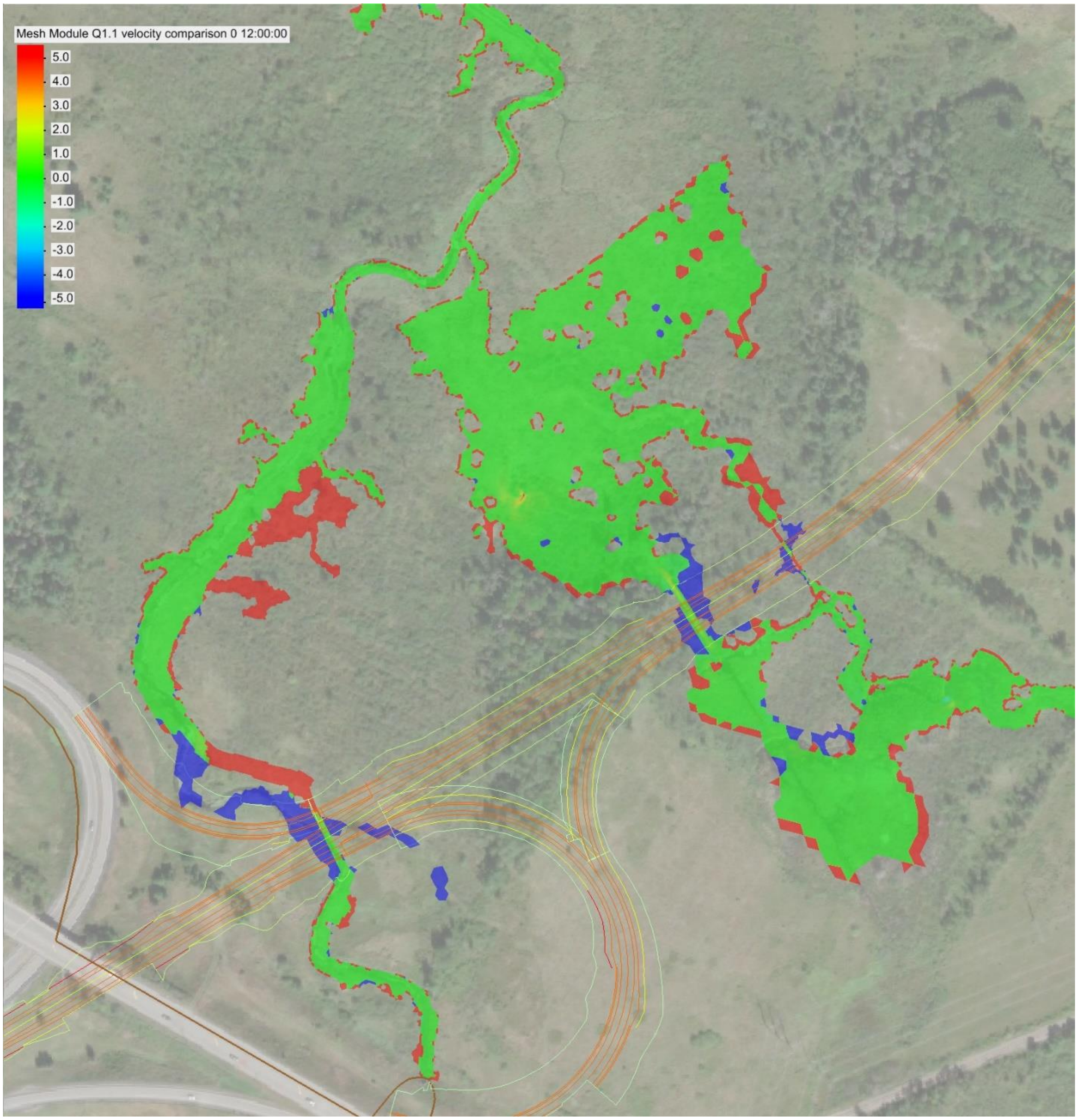

Figure 23: Q1.1 Change in Velocity from Existing to Proposed

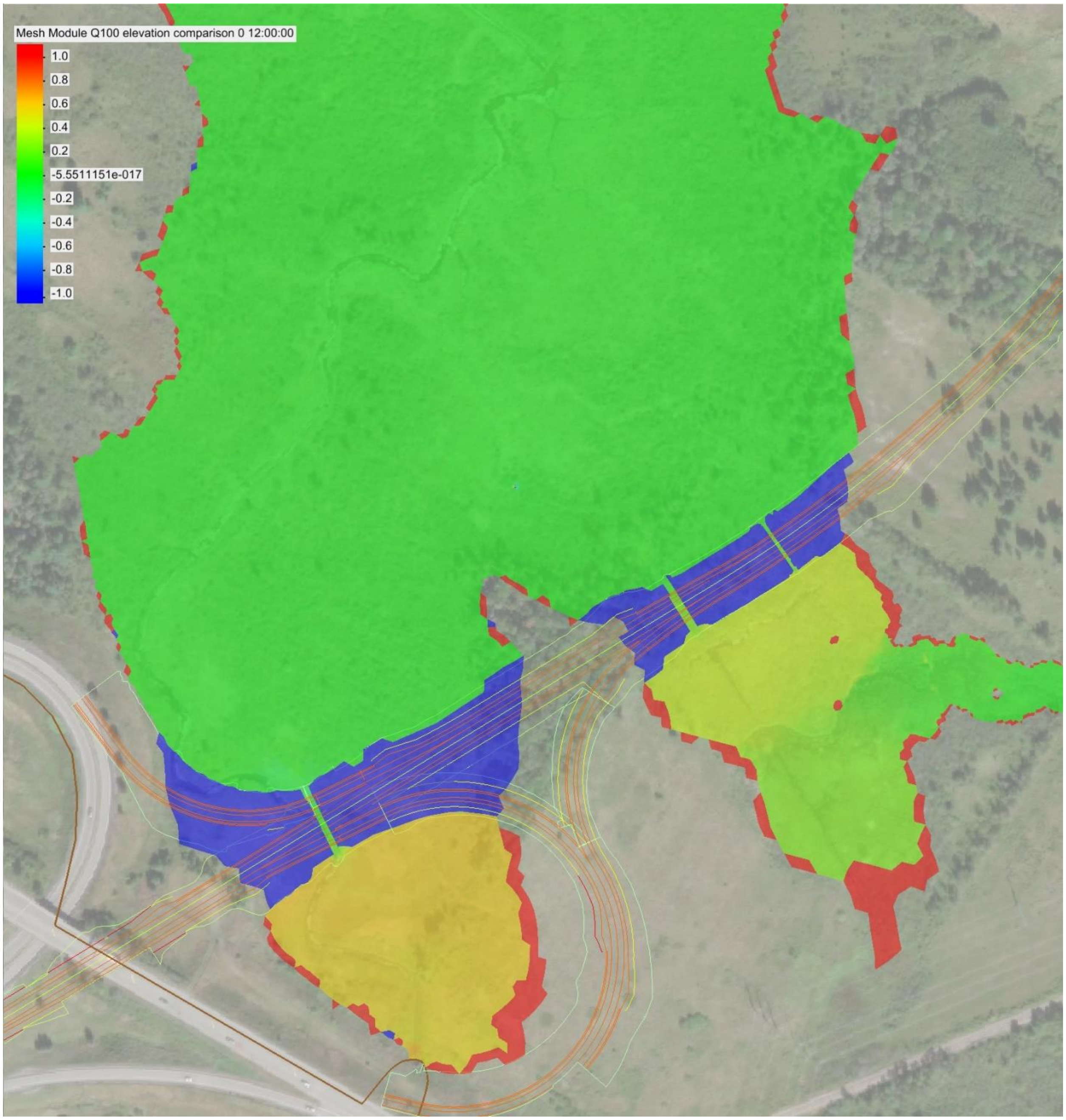

Figure 24: Q100 Change in Water Surface Elevations from Existing to Proposed

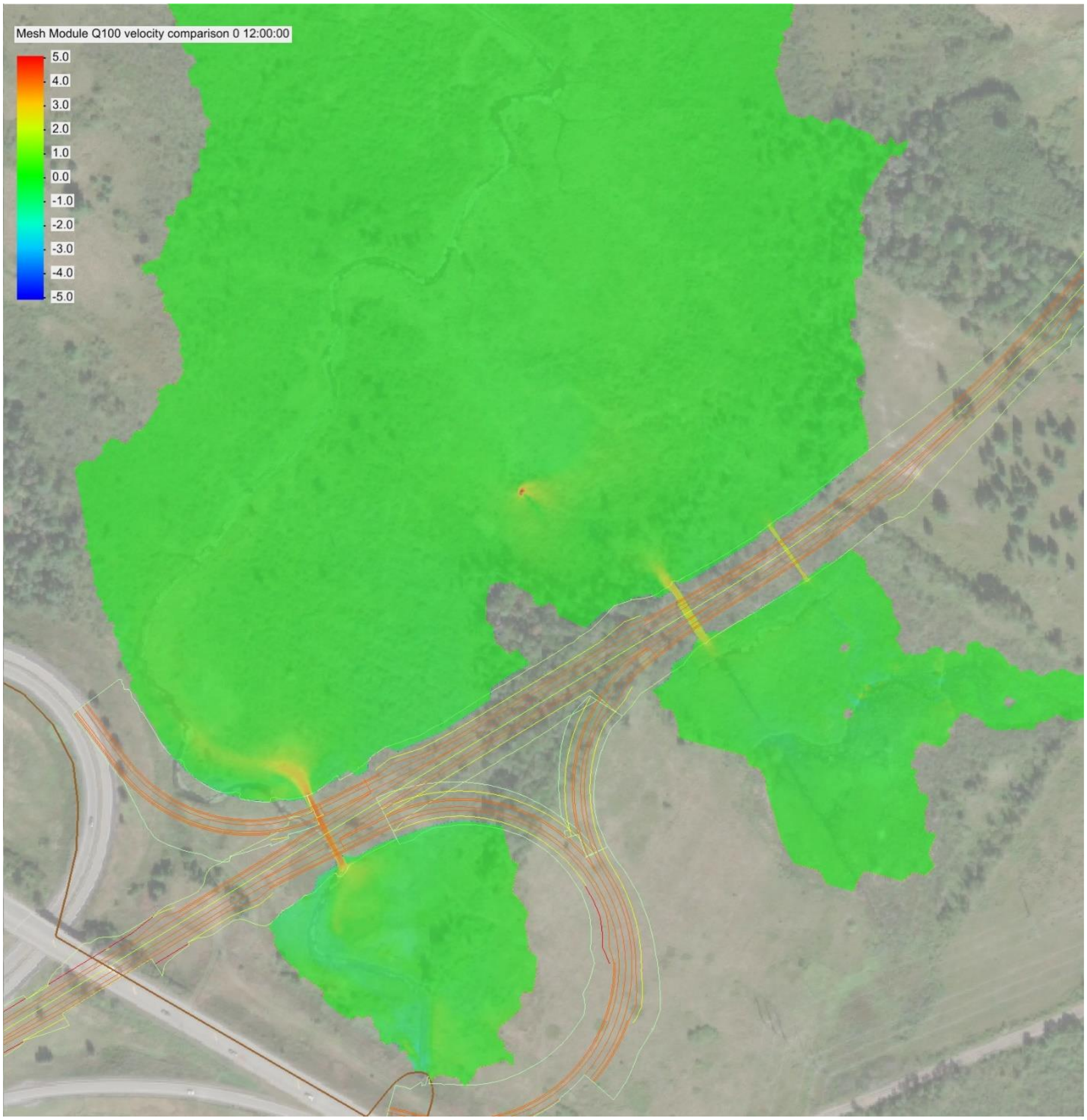

Figure 25: Q100 Change in Velocity from Existing to Proposed

Stream Stability and Scour Evaluation

The low velocities present should not present any risk for scour. A revegetation plan will be developed for the reconstructed stream channel to protect against erosion.

Environmental Considerations

No species specific velocity requirements are present on this project. Bank-full widths and bank requirements were determined as part of the EIS prepared by MaineDOT and FHWA for this project. The Felts Brook structure will be 1.2 Bank-Full Width and the Tributary structure will have 6'-6" wide banks and 13' of head clearance over them for large mammal passage.

Conclusion

The performance of the culvert is evaluated on the four criteria given in the project summary:

1. Changes in elevations, flooding extent, and velocities at Q1.1 are small and not significant.
2. The largest elevation change at Q100 is +0.6 feet, but this is trapped between Route 1A and Ramp E, so there are no property impacts. The upstream flooded area for the Tributary has a raise of 0.4 feet, with the change in total area small and in areas covered by forest/scrub.
3. The change in velocity for Q100 is significant, but less than 5 feet per second. Outside of the culvert, the maximum stream velocity is less than 5 feet per second and drops quickly, so with armored banks at the exit, risk of scour is minimal.
4. The Hw/D ratio of the Felts Brook culvert is 0.9 at Q100, meeting the criteria. The Hw/D ratio for the Tributary is significantly smaller.

The comparison between existing and proposed results shows that the proposed culverts impact the backwater height and stream velocities, but that the increases are reasonable for new embankment construction channeling a wide floodplain through smaller structures. Riprap in the banks and bottom fill layer are recommended in the Felts Brook culvert for stability during larger flood events.

Summary of Results

		Existing		Proposed Structure	
		Felts Brook	Tributary	Felts Brook	Tributary
Total Area of Waterway Opening	ft^2	N/A	N/A	155	290
Headwater elevation @ $Q_{1.1}$	ft	80.2	81.1	80.1	81.2
Headwater elevation @ Q_{10}	ft	81.7	81.8	81.9	82.1
Headwater elevation @ Q_{25}	ft	82.1	82.1	82.5	82.6
Headwater elevation @ Q_{50}	ft	82.4	82.4	82.9	82.8
Headwater elevation @ Q_{100}	ft	82.8	82.8	83.4	83.2
Headwater elevation @ Q_{500}	ft	83.8	83.8	84.6	84.1
Hw/D Ratio @ Q_{100}	ft	N/A	N/A	0.9	0.3
Hw/D Ratio @ Q_{500}	ft	N/A	N/A	1.1	0.4
Outlet Velocity @ $Q_{1.1}$	ft/s	0.9	0.9	0.9	2.6
Outlet Velocity @ Q_{10}	ft/s	1.0	0.6	2.9	2.8
Outlet Velocity @ Q_{25}	ft/s	0.8	0.4	3.5	2.9
Outlet Velocity @ Q_{50}	ft/s	0.7	0.3	4.0	2.9
Outlet Velocity @ Q_{100}	ft/s	0.6	0.3	4.4	2.9
Outlet Velocity @ Q_{500}	ft/s	0.5	0.2	5.2	2.8

Reported by: Joshua Hasbrouck
Date: September 11, 2020

Note: All elevations based on North American Vertical Datum (NAVD) of 1988.

Hydraulic Report

Route 9 over

Eaton Brook

Brewer, Maine

Federal Project No. 1891500

WIN 018915.00

Maine Department of Transportation
Bridge Program

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Hydrology Report

Watershed Description

Eaton Brook flows north from Holden to the Penobscot River. The majority of the watershed is wooded, with some low-lying marshy areas and cleared fields.

Figure 1: StreamStats watershed for Eaton Brook at study site

Nature of Flood Risk

Periodic seasonal flooding over the stream banks is typical for flatter areas of the watershed. The area of interest is well outside of the influence of the Penobscot River for flooding. There is beaver activity in the area which may affect results for typical seasonal flooding, but is not expected to affect design flood results.

Previous Hydrologic Studies in Watershed

The FEMA Flood Insurance Study for the City of Brewer, Maine (1977) gives 1% recurrence flood flows for Eaton Brook at the confluence with the Penobscot River, but the detailed study limits do not extend upstream to the project site. The Flood Insurance Rate Map for the City of Brewer (Community-Panel Number 230104 0005 B, 1978) gives approximate flooding limits but no elevations for Eaton Brook at the project.

Current Flow Data

Current flow data at the site of the proposed Route 9 alignment was calculated by the Maine DOT Environmental Office Hydrology Section using the U.S.G.S. regression equations (Hodgkins 1999 and Lombard/Hodgkins 2015).

Summary of watershed and flows

Drainage Area	13.2	mi^2
Q1.1	185.5	ft^3/s
Q10	733.6	ft^3/s
Q25	939.3	ft^3/s
Q50	1100.5	ft^3/s
Q100	1273.7	ft^3/s
Q500	1700.6	ft^3/s

Table 1: Summary of watershed and flows

Hydraulic Report

Introduction

This report was prepared for MaineDOT to evaluate the hydraulics of the proposed bridge carrying the new Route 9 connector over Eaton Brook. The models for both the existing conditions with no roadway or structures and the proposed roadway and crossing structure are described below.

Model Development

The model was limited to the area that had been surveyed for the project, since that area was sufficient for setting a reasonable upstream and downstream boundary. As a result, no additional LiDAR data was used, although it was available for the surrounding topography.

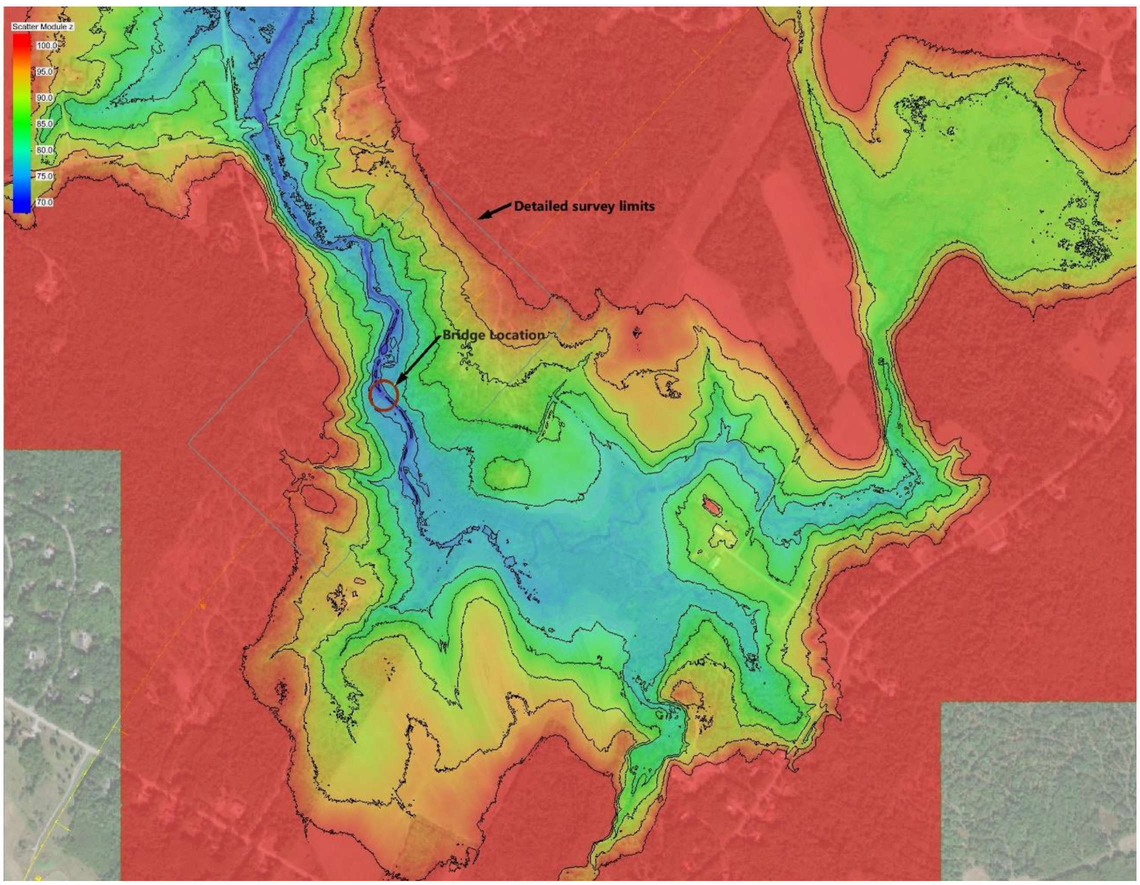

Figure 2: Existing terrain model with color filled contours overlaid on satellite photo

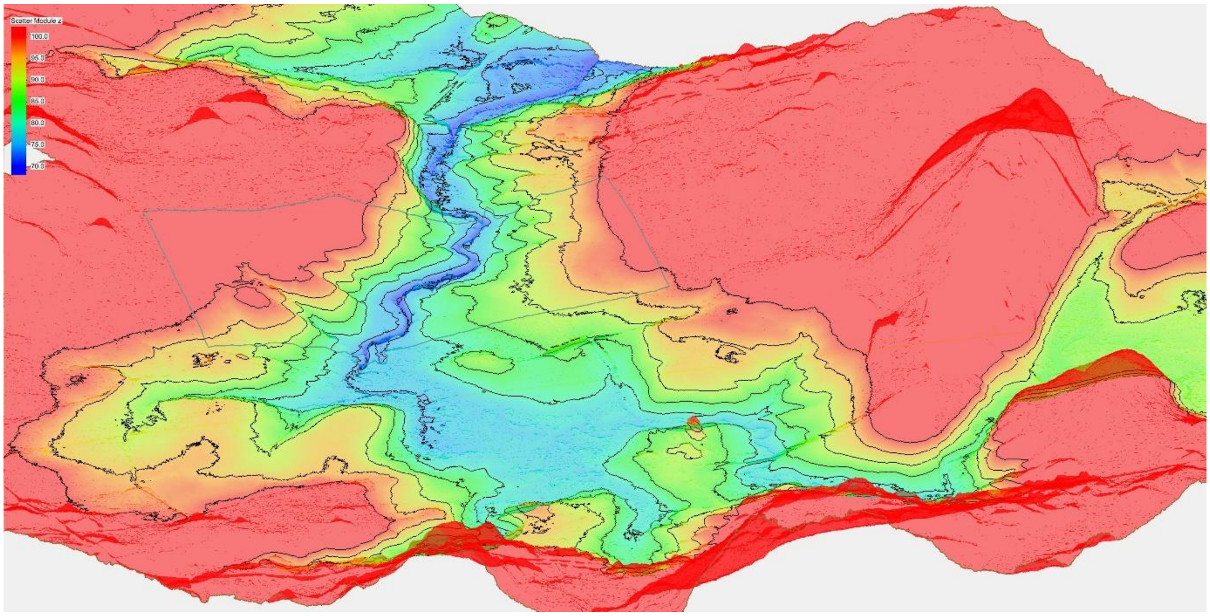

Figure 3: 3D view of existing terrain model

The developed mesh has 8770 elements and covers 51.3 acres. The mesh density is variable, with spacings of 100 feet on the outside boundaries and 5-10 feet on the channel elements. Most of the mesh uses triangular elements, but the channel is defined using rectangular elements with an approximate 2:1 length to width ratio aligned parallel to the flow direction. One area of the channel uses triangular elements to more accurately define the grade changes at a beaver dam. When using the built-in mesh check tools in SMS, a significant number of elements are labeled as having the mesh quality issue “Maximum slope”, but this appears to be primarily due to the terrain, not an issue with the mesh creation. A dataset calculating the difference between the mesh and the underlying elevation scatter set to check that the mesh accurately reflects the ground surface shows an excellent correlation.

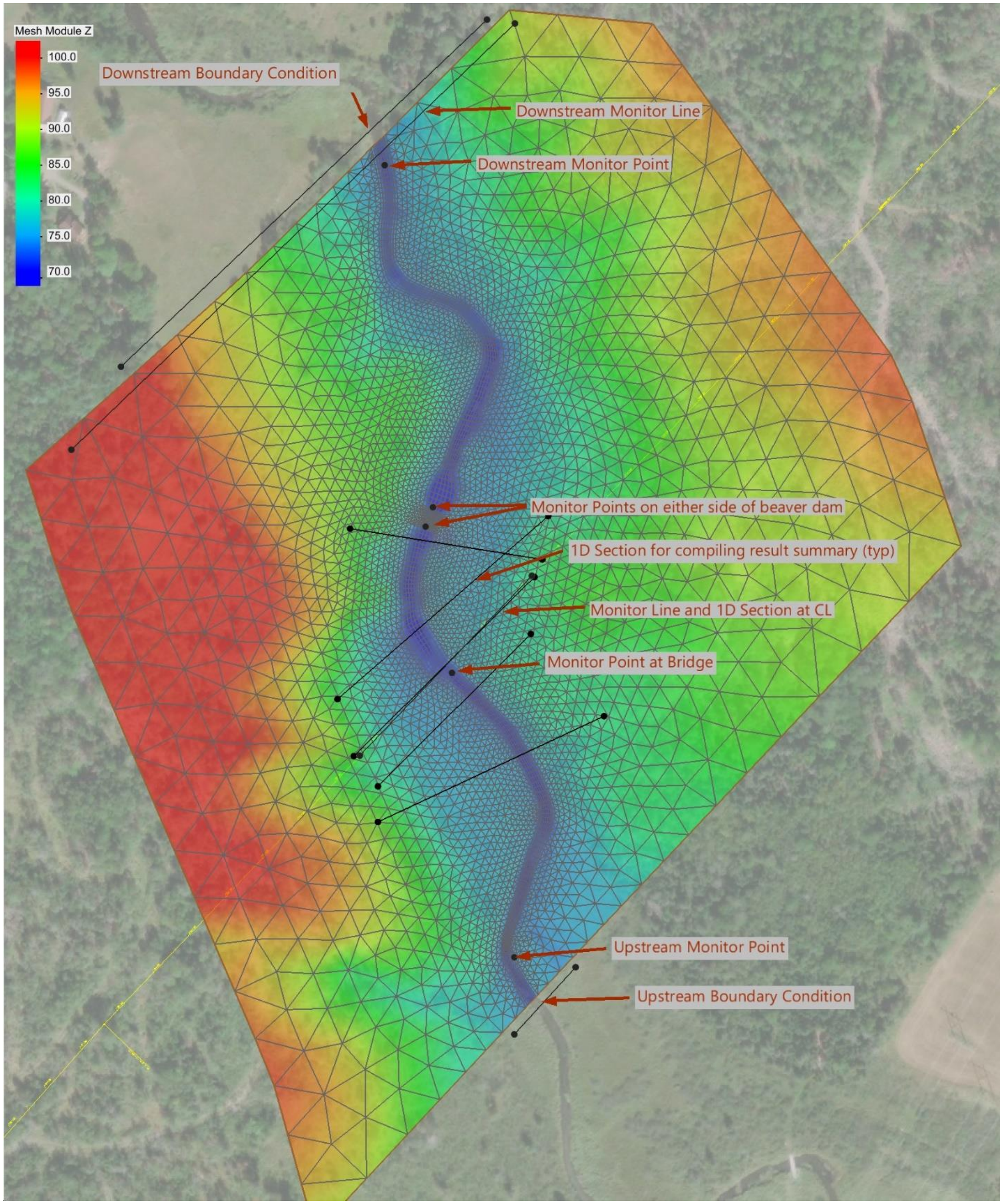

Figure 4: Existing model mesh and coverages labelled to show monitor points and 1D sections where results were checked

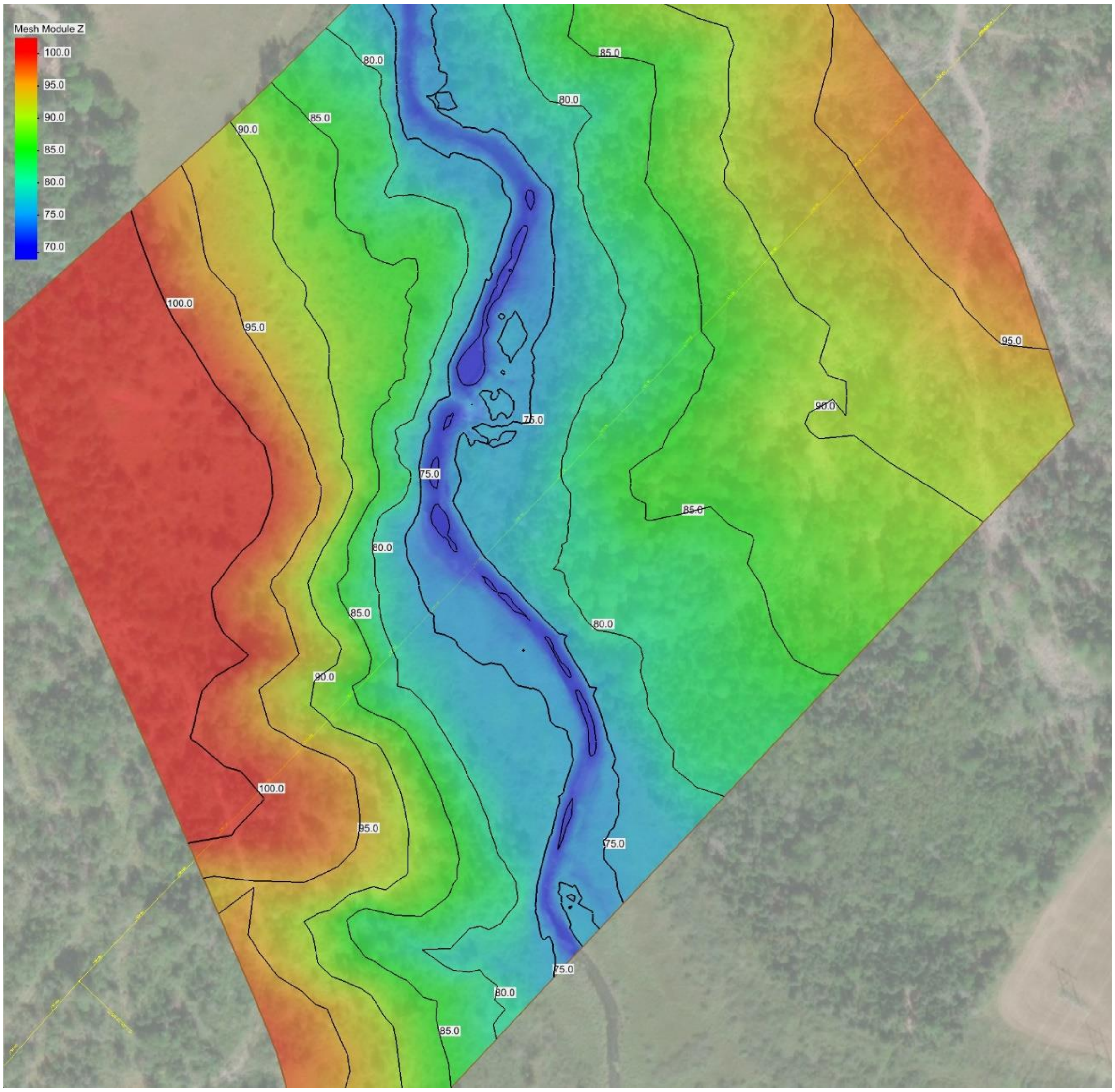

Figure 5: Existing model mesh contours showing elevations

The inflow boundary condition is an Inlet-Q (defined flow) line set at the upstream limits of the model. The exit boundary is an Exit-H (set elevation) line. The downstream water elevation was estimated using the built-in tool in SMS that calculates a starting elevation based on the downstream slope and an estimated roughness. For this model, the downstream values used were 0.6 for the composite Manning's n and 0.0016 for the stream slope. The stream slope was estimated by measuring in the LiDAR data the change in elevation of the stream bank between the model boundary and the next downstream bridge. To evaluate whether the model was sensitive to changes in the downstream boundary condition, the Q100 flow was run with the downstream boundary elevation varied by ±0.5 feet. The change in water elevation at the proposed structure location was about 3 inches in magnitude, so the model is somewhat sensitive to changes in the downstream boundary condition, but the accuracy is still within an acceptable range.

The model uses a Manning's n in the channel of 0.04, 0.12 for forested areas, 0.06 for scrub and brush, and 0.035 for grassy floodplain. The model's sensitivity to changes in the roughness was tested by running the Q100 flow and boundary condition multiple times with a single roughness value adjusted up or down by 0.005 each time. All changes to water elevations were less than 1 inch in magnitude at the proposed structure locations, so the model is not sensitive to changes in roughness.

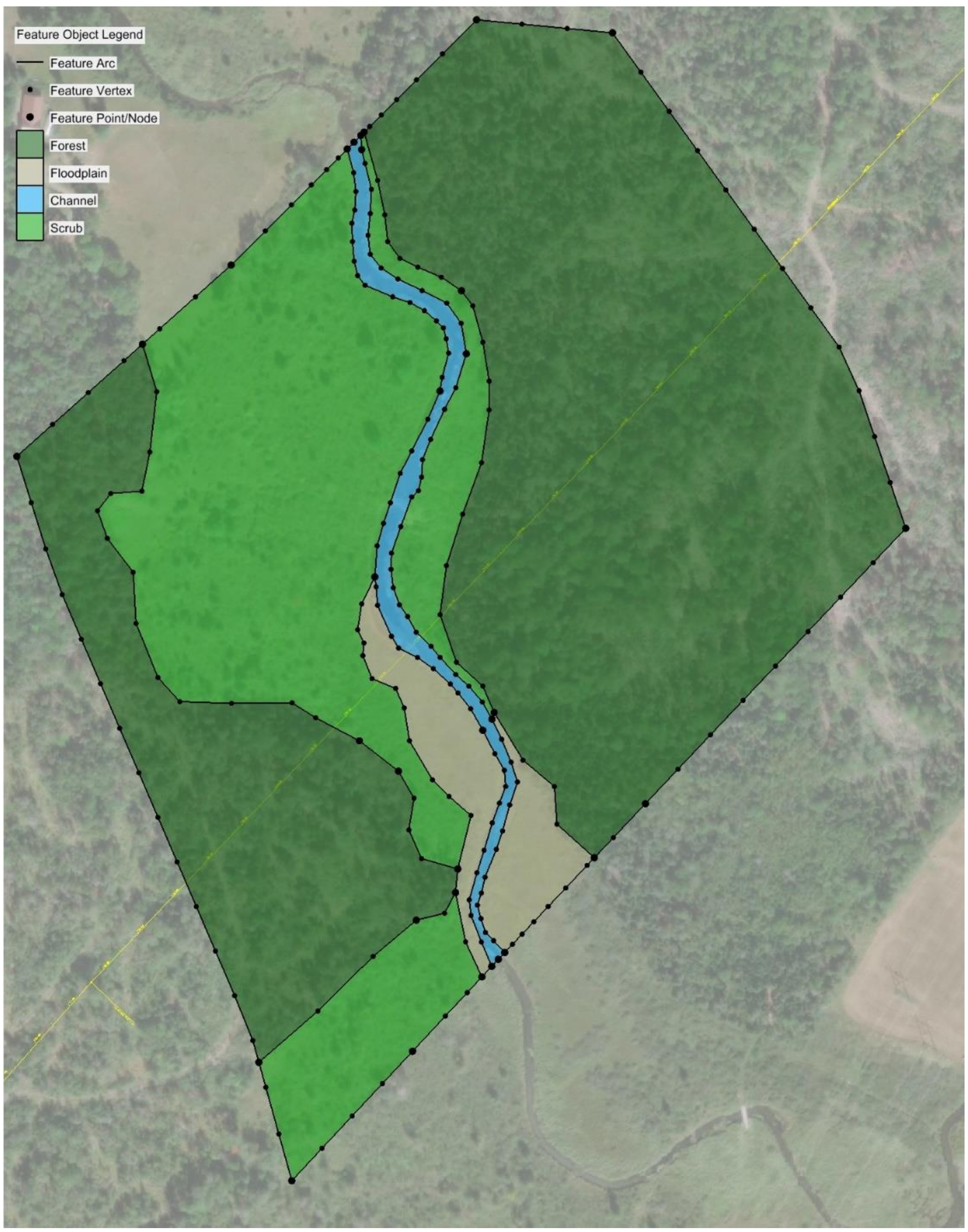

Figure 6: Roughness assignments for the existing model

No data was available for calibration except checking flooding limits against where they would be expected based on the terrain and vegetation type. The Q1.1 flow floods the grassy area that would be expected to flood nearly every year, and the Q10 flow floods up just into the tree line, which both make sense as natural limits.

To check whether the run time was long enough, the flows through the monitor lines were checked to see how closely the values converged. For all flows, a run time of 2 hours with a time step of 5 seconds and an initial condition of “dry” was sufficient to reach convergence and stable results.

Once the existing model had been tested for sensitivity and calibration, a proposed model terrain was created by adding the roadway and bridge embankments to the model using the Feature Stamping tool in SMS. Because of the limitations of the tool, this was done in two stages, first to create the animal passage paths on each bank, then to superimpose the roadway embankment on top of that. The mesh definition was adjusted by adding lines along the roadway embankment to ensure the mesh would break smoothly at that point and accurately represent elevations.

The material roughness assignments were adjusted so that the roadway embankment was defined as cleared grassy area. Since the flood elevations will not reach the top of the roadway embankment, a separate material was not defined for the pavement surface.

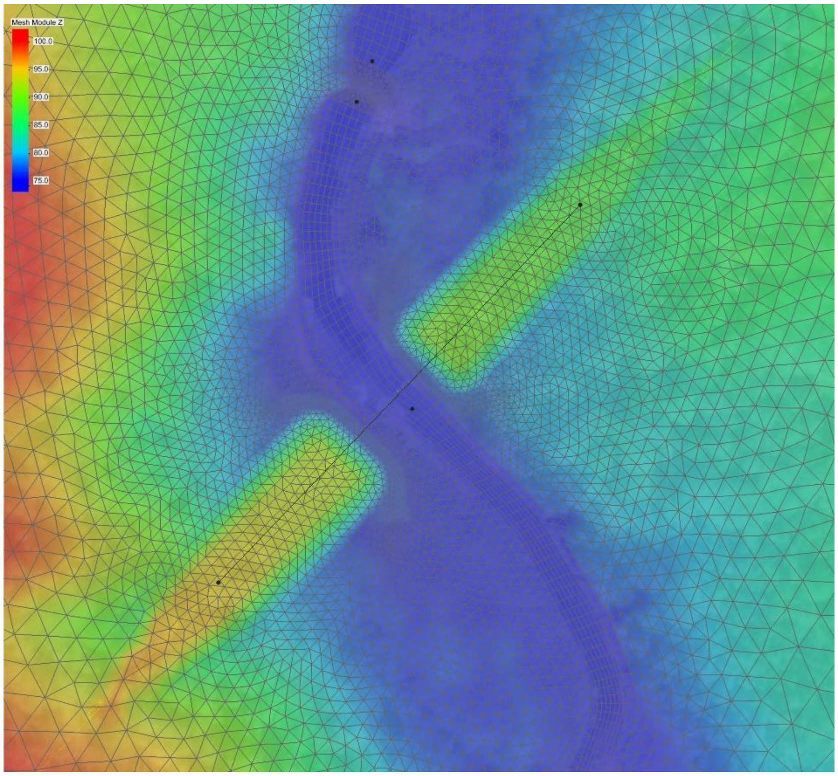

Figure 7: Detailed view of mesh at the bridge for the proposed condition with color assigned by elevation

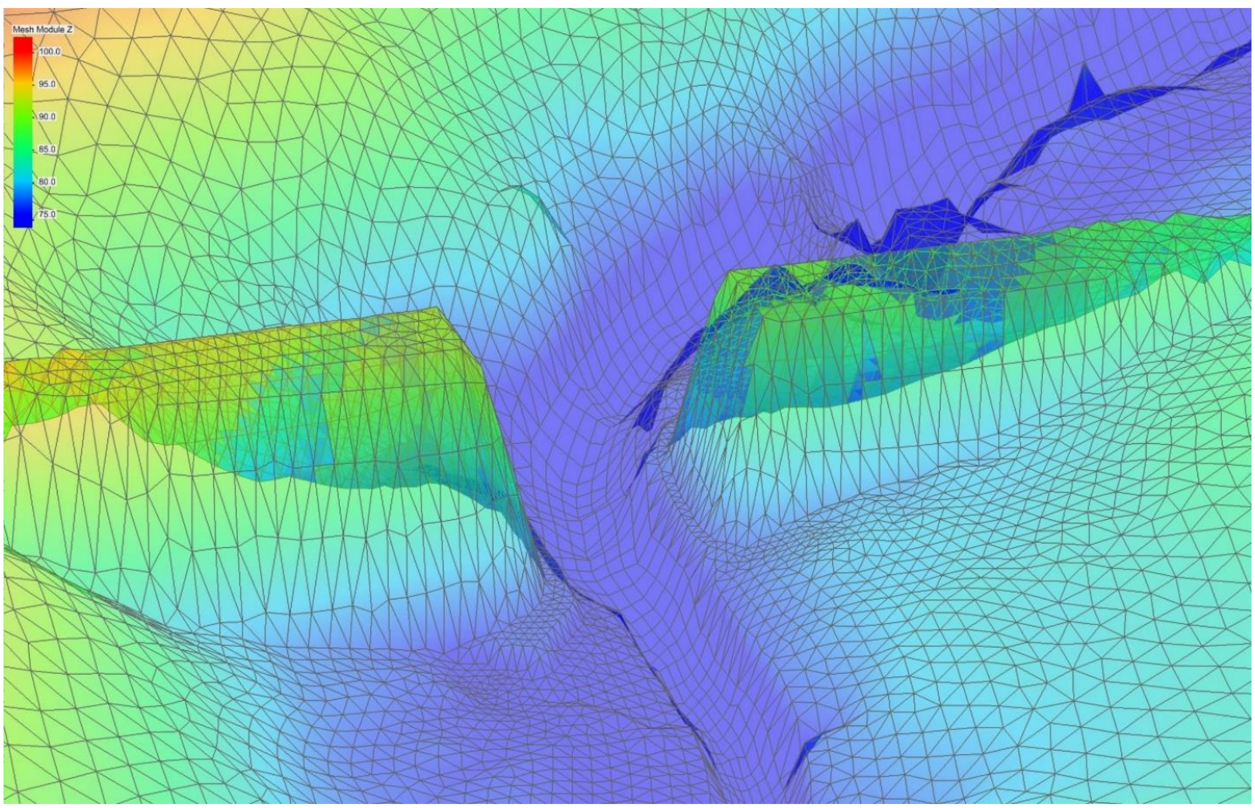

Figure 8: 3D view of proposed model mesh at bridge

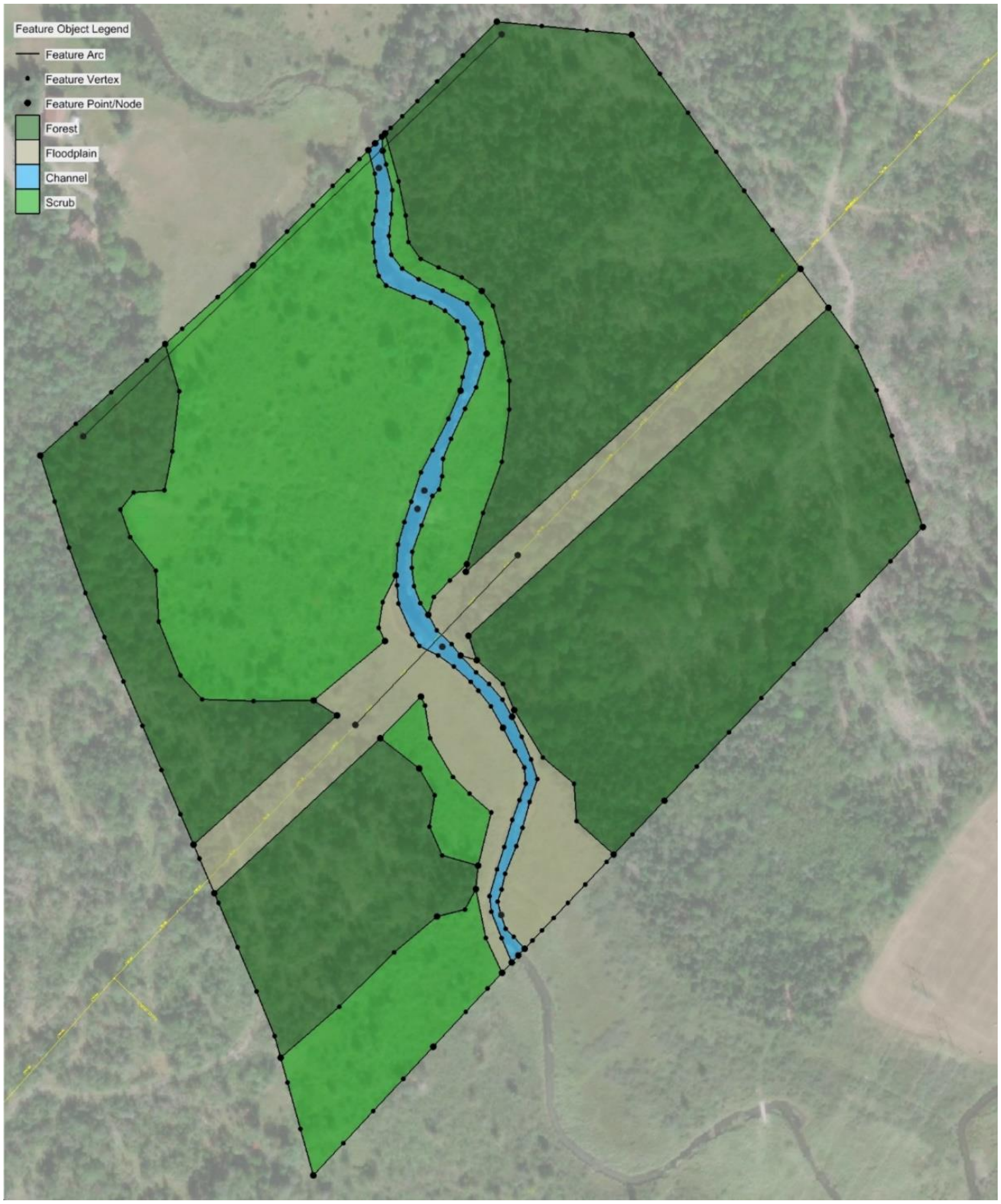

Figure 9: Roughness assignments for the proposed model

Addendum On Updated Survey Information

After this report was originally written, a discrepancy was discovered with some photogrammatric survey data in areas with tall grass. Those areas were resurveyed in January 2020. The areas affected at this site were small. An updated mesh was created for both the existing and proposed conditions and the Q100 results were recalculated and compared to the original results. Since changes in the results were on the order of 0.001 or smaller, the updated survey had no measurable effect on the results and the original results are reported here.

Hydraulic Analysis Results for Existing Conditions

The existing model gives an elevation of just over 79 feet for the Q100 flood elevation, with velocities less than 2 feet per second at the proposed bridge location. Q1.1 results are an elevation just over 75 feet with velocities less than 1 foot per second.

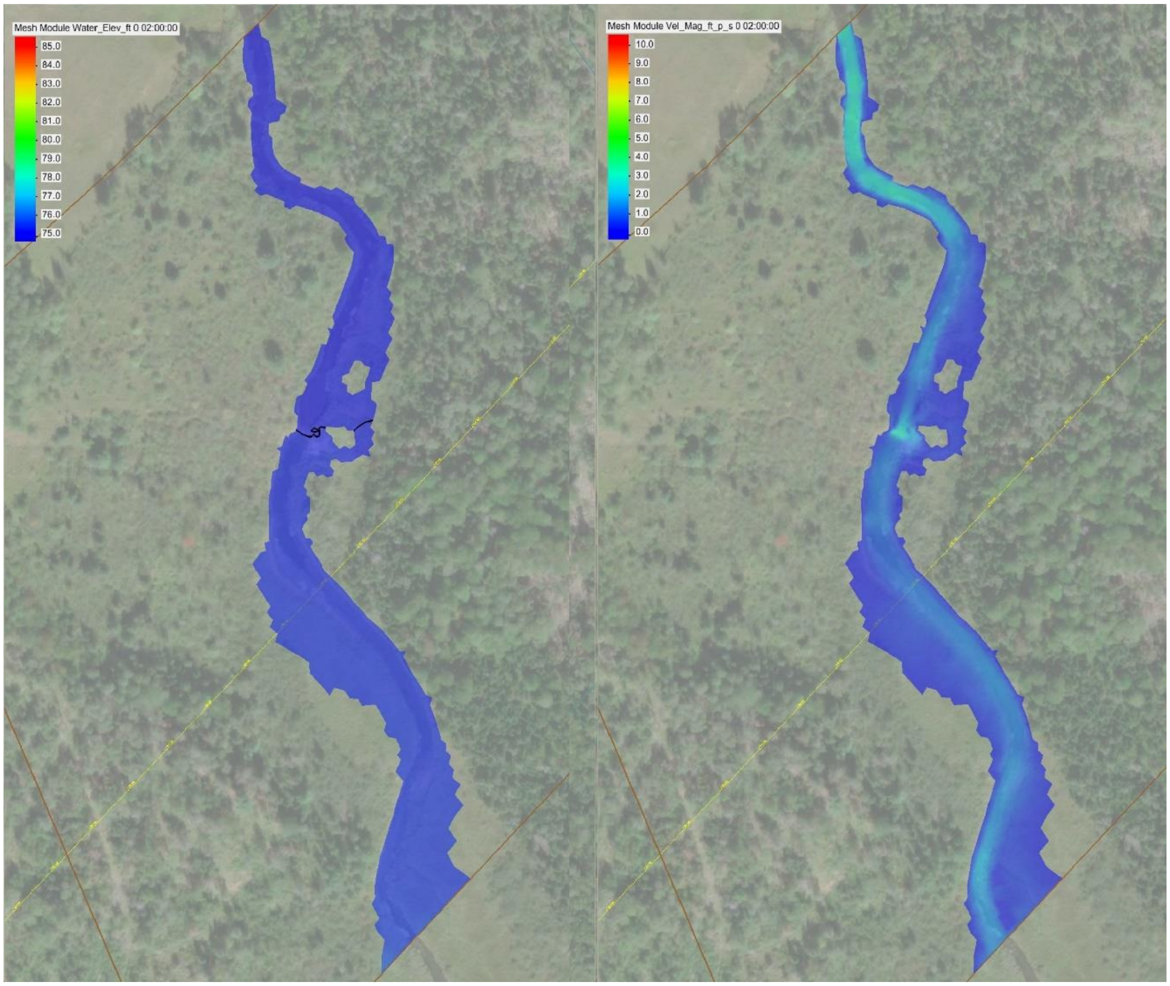

Figure 10: Existing Q1.1 Water Surface Elevations and Velocities

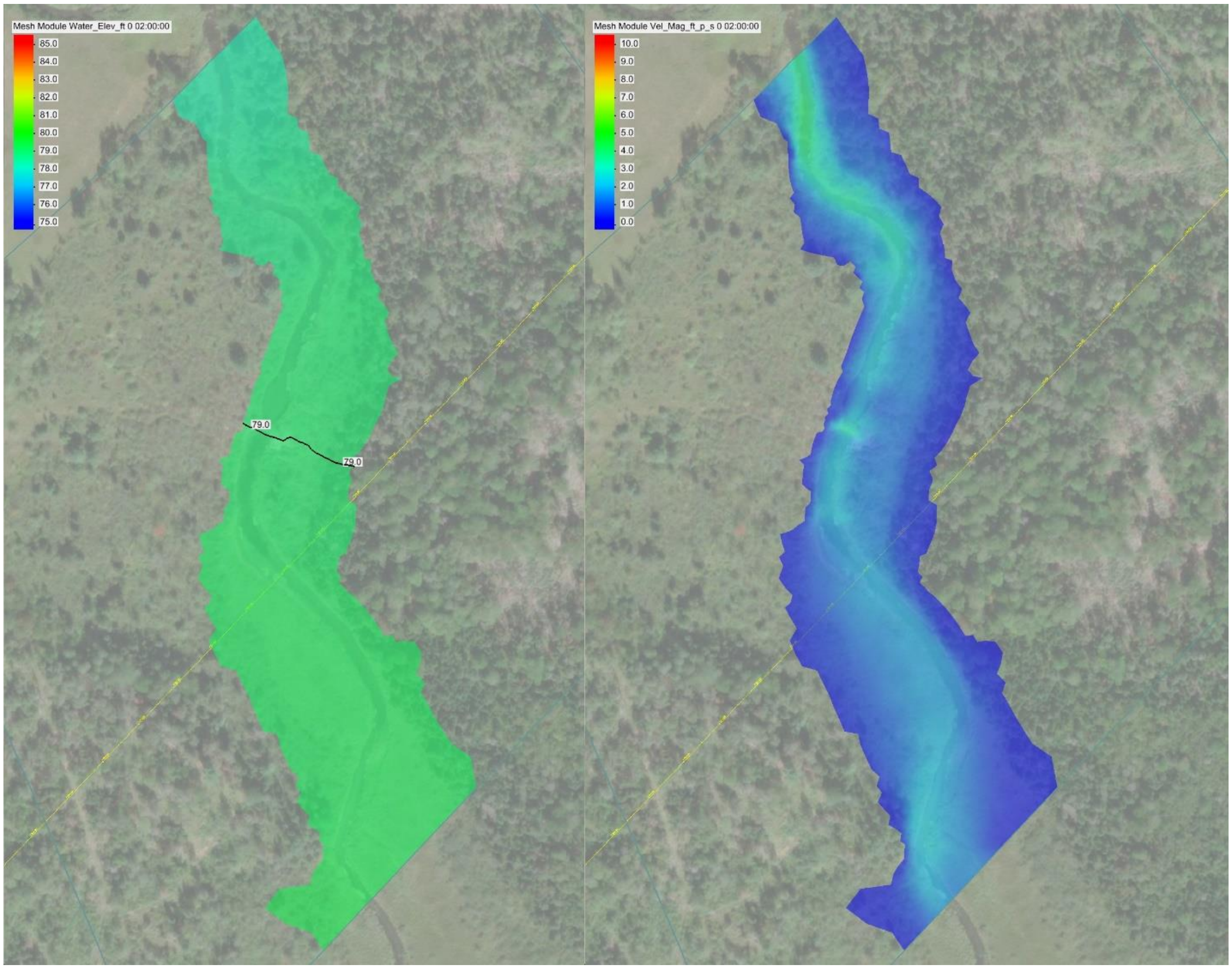

Figure 11: Existing Q100 Water Surface Elevations and Velocities

Hydraulic Analysis Results for Proposed Conditions

For the proposed condition, the primary results reported are the comparison to the existing model. Images are shown for Q1.1 and Q100 comparisons, where green values are essentially the same as existing, blue areas are where the proposed model blocked off flow, and red areas are additional areas flooded by the proposed model.

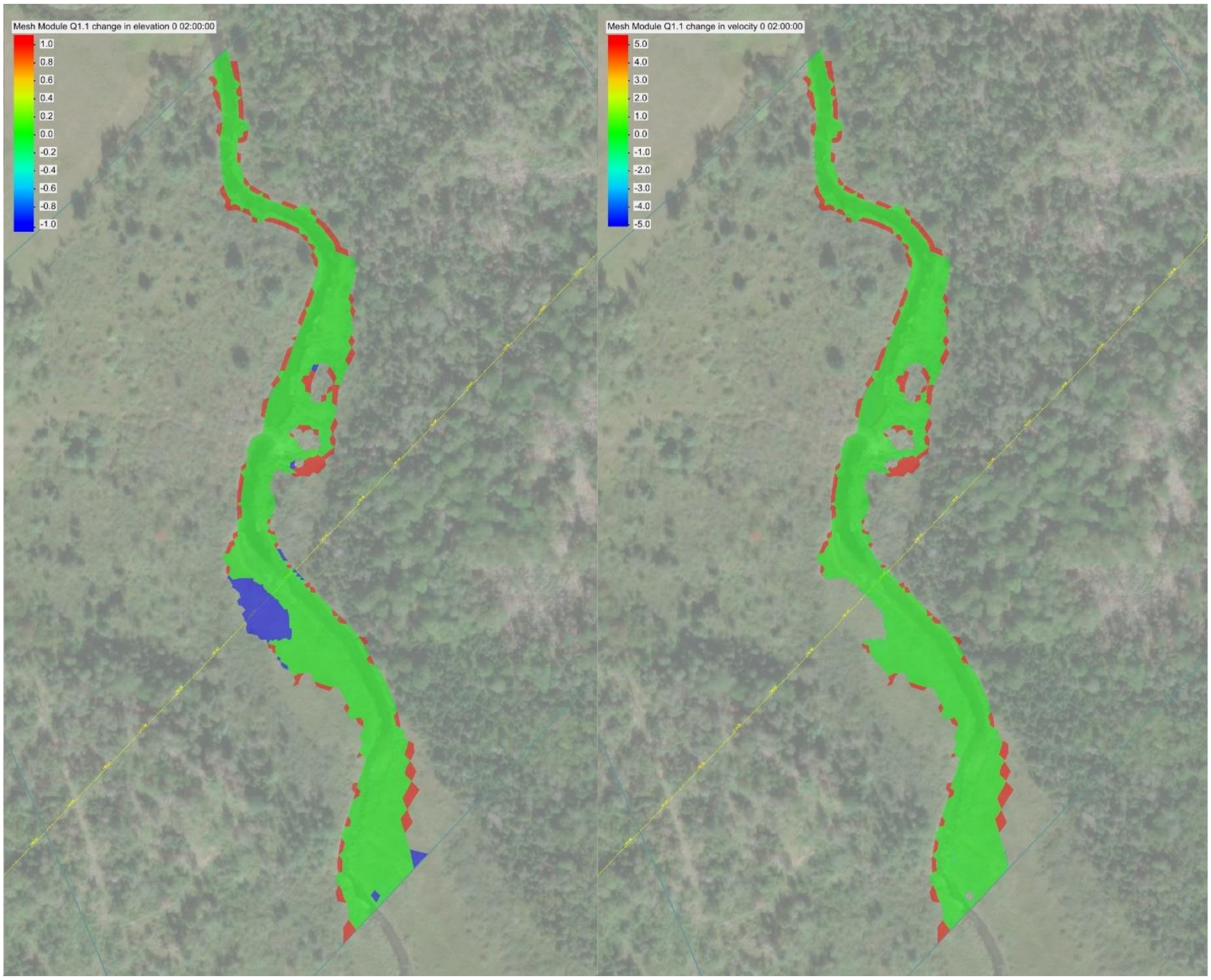

Figure 12: Q1.1 Change in Water Surface Elevation and Velocity from Existing to Proposed

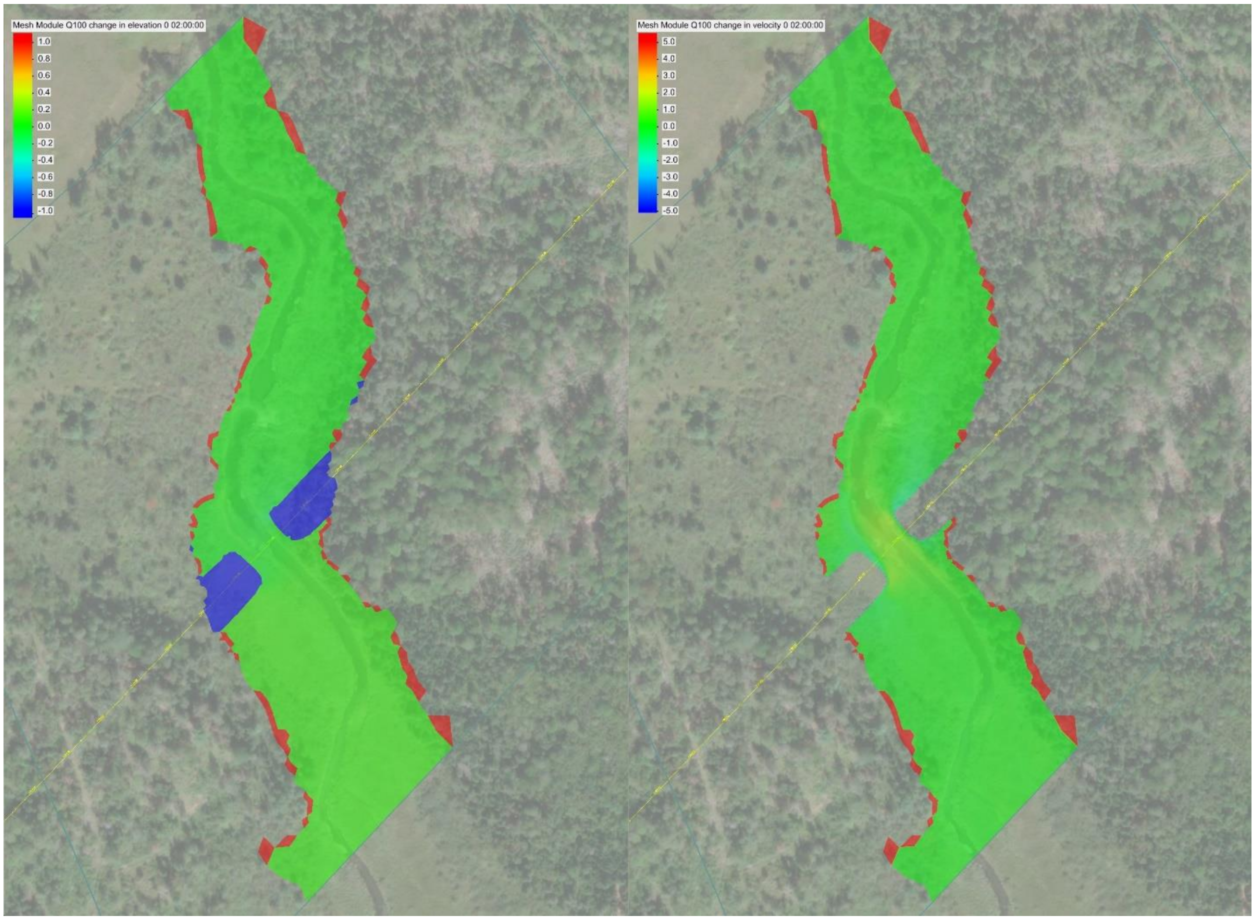

Figure 13: Q100 Change in Water Surface Elevation and Velocity from Existing to Proposed

Changes in elevation and velocity are virtually undetectable for Q1.1 results. The velocity increases by around 1.2 feet per second at the bridge for Q100, but the elevation remains essentially the same.

Stream Stability and Scour Evaluation

The low velocities present should not present any risk for scour. New embankment slopes in the floodplain will be protected from erosion by riprap.

Environmental Considerations

No species specific velocity requirements are present on this project. Bank-full widths and bank requirements were determined as part of the EIS prepared by MaineDOT and FHWA for this project. The specified BFW is 30 feet with 6.5 foot wide banks, but because of bridge sizing requirements and the site topography the actual widths will be wider.

Conclusion

The performance of the bridge is evaluated on the four criteria given in the project summary:

1. Changes in elevations, flooding extent, and velocities at Q1.1 are within the range of a rounding error and not significant.
2. The elevation change at Q100 is not significant, avoiding any property impacts.
3. The change in velocity for Q100 is measurable, but does not present an issue for stream stability.
4. The clearance between the design flood and the low chord is greater than 5 feet, which is well above the required 2 feet.

The comparison between existing and proposed results shows that the proposed bridge has a minimal impact on flow through the structure. All the hydraulic design criteria are met, and no issues that would require changes in the bridge design have been identified.

Summary of Results

		Existing	Proposed Structure
		No Bridge	121' Single Span
Total Area of Waterway Opening	ft^2	N/A	6137
Headwater elevation @ $Q_{1.1}$	ft	75.2	75.2
Headwater elevation @ Q_{10}	ft	77.6	77.7
Headwater elevation @ Q_{25}	ft	78.3	78.3
Headwater elevation @ Q_{50}	ft	78.7	78.7
Headwater elevation @ Q_{100}	ft	79.1	79.2
Headwater elevation @ Q_{500}	ft	79.9	80.0
Underclearance @ Q_{100}	ft	N/A	5.8
Underclearance @ Q_{500}	ft	N/A	5.0
Outlet Velocity @ $Q_{1.1}$	ft/s	1.0	1.1
Outlet Velocity @ Q_{10}	ft/s	1.6	2.3
Outlet Velocity @ Q_{25}	ft/s	1.7	2.6
Outlet Velocity @ Q_{50}	ft/s	1.7	2.8
Outlet Velocity @ Q_{100}	ft/s	1.8	2.9
Outlet Velocity @ Q_{500}	ft/s	2.0	3.3

Reported by: Joshua Hasbrouck
Date: October 10, 2019

Note: All elevations based on North American Vertical Datum (NAVD) of 1988.

Hydraulic Report

Route 9 over
Unnamed Eaton Brook Tributary
Brewer, Maine

Federal Project No. 1891500
WIN 018915.00

Maine Department of Transportation
Bridge Program

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Watershed Description

Unnamed Eaton Brook Tributary flows north from Eddington to join with Eaton Brook in Brewer before flowing to the Penobscot River. The area of interest to this project is close to where the power lines cross the stream. Most of the watershed is wooded, with low lying marshy areas along the stream, large wetland areas upstream, and some cleared areas along the powerlines.

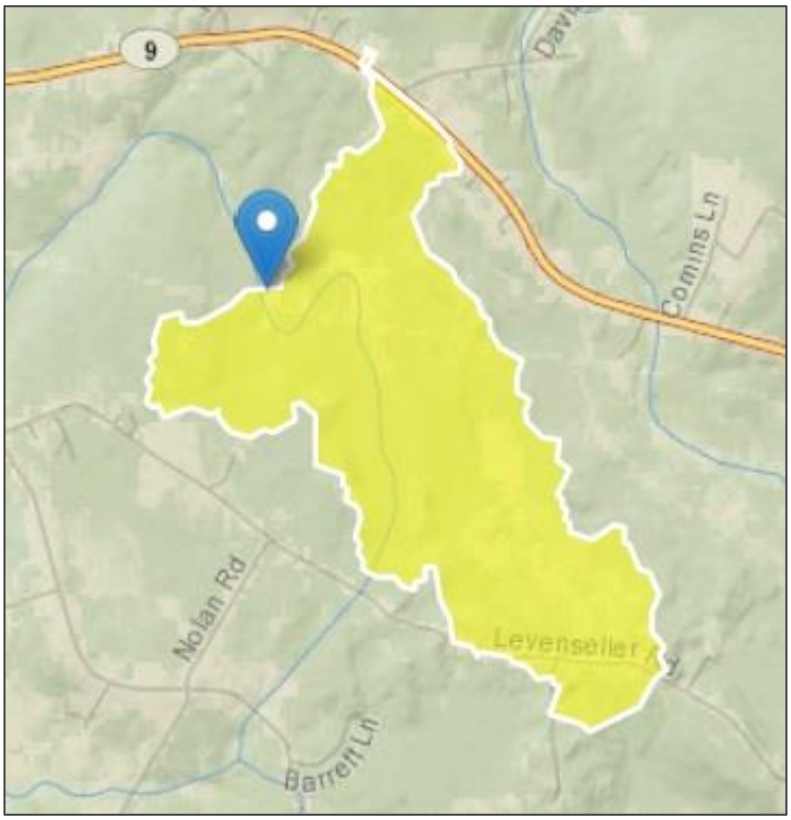

Figure 1: StreamStats watershed for Unnamed Eaton Brook Tributary at study site

Nature of Flood Risk

Periodic seasonal flooding over the stream banks is typical for flatter areas of the watershed. The area of interest is well outside of the influence of the Penobscot River for flooding. Tree line in wetland areas is considered an indicator of the limits of frequent flooding.

Previous Hydrologic Studies in Watershed

No detailed flood analysis was located. The Flood Insurance Rate Map for the Town of Eddington (Community-Panel Number 230382 0005 B, 1978) gives approximate flooding limits but no elevations at the project.

Current Flow Data

The hydrology for this site was calculated from the USGS regression equations for Maine (Hodgkins/Lombard). Based on the calculated bank-full width being significantly less than observed and the model not flooding the area expected from observation of vegetation types, it appears that these flows could be significantly lower than the actual flows. Both the watershed area and the wetlands percentage are outside the range that the regression equations are validated for, increasing the inaccuracy of the calculated flows. In addition, the regression values can vary by up to 50% within the 68% confidence limit, and outliers may vary even more. Based on this, the calculated regression flows are likely understating the actual flows by a substantial amount, and the model analyses reported were run with values increased by 50%. This increase was used first as a trial value, and since it did not result in obviously excess flooding was carried through the rest of the analysis.

Summary of watershed and flows

	Regression	Increased 50%	
Drainage Area	1.40		mi^2
Q1.1	18.4	27.6	ft^3/s
Q10	64.7	97.0	ft^3/s
Q25	84.6	126.9	ft^3/s
Q50	95.0	142.5	ft^3/s
Q100	111.1	166.7	ft^3/s
Q500	143.9	215.8	ft^3/s

Table 1: Summary of watershed and flows

Hydraulic Report

Introduction

This report was prepared for MaineDOT to evaluate the hydraulics of the proposed culvert under the new Route 9 connector at an unnamed tributary of Eaton Brook. The models for both the existing condition with no roadway or structures and the proposed roadway and crossing structure are described below.

Model Development

For better accuracy in the water elevation results, the model was limited to an area that detailed ground survey had been done in the channel. Some low-lying areas that were expected to flood were not included in the project survey, so additional LiDAR data was used to expand the model limits to cover those areas.

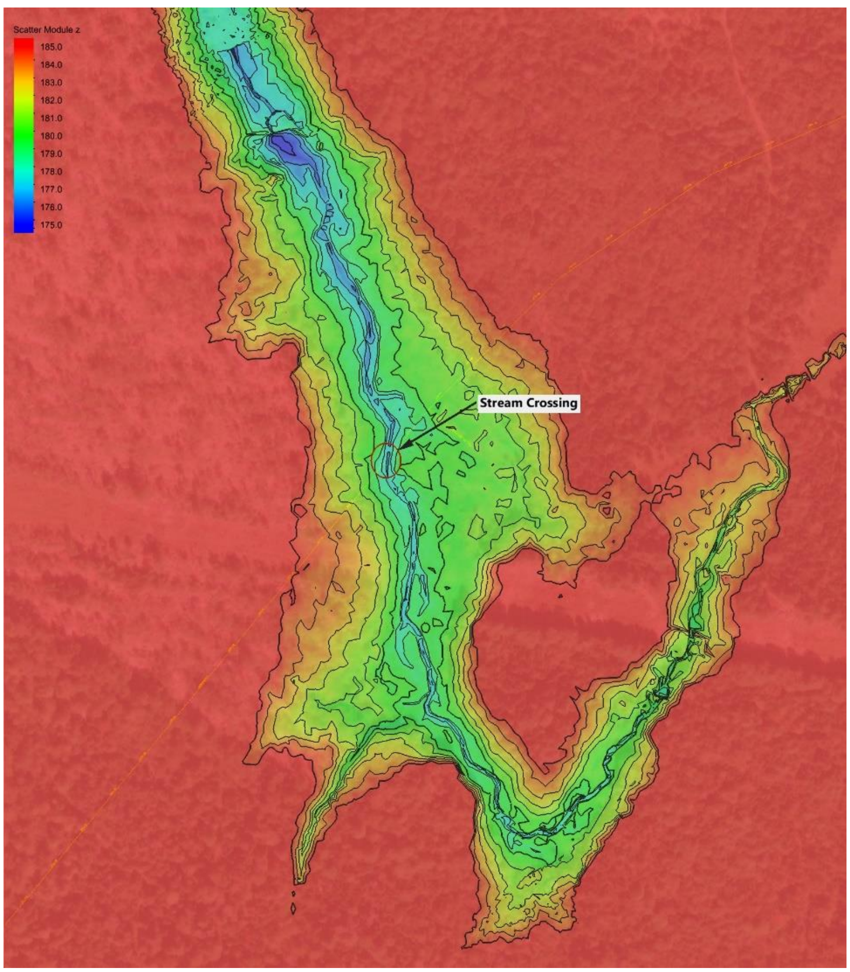

Figure 2: Existing terrain model with color filled contours overlaid on satellite photo

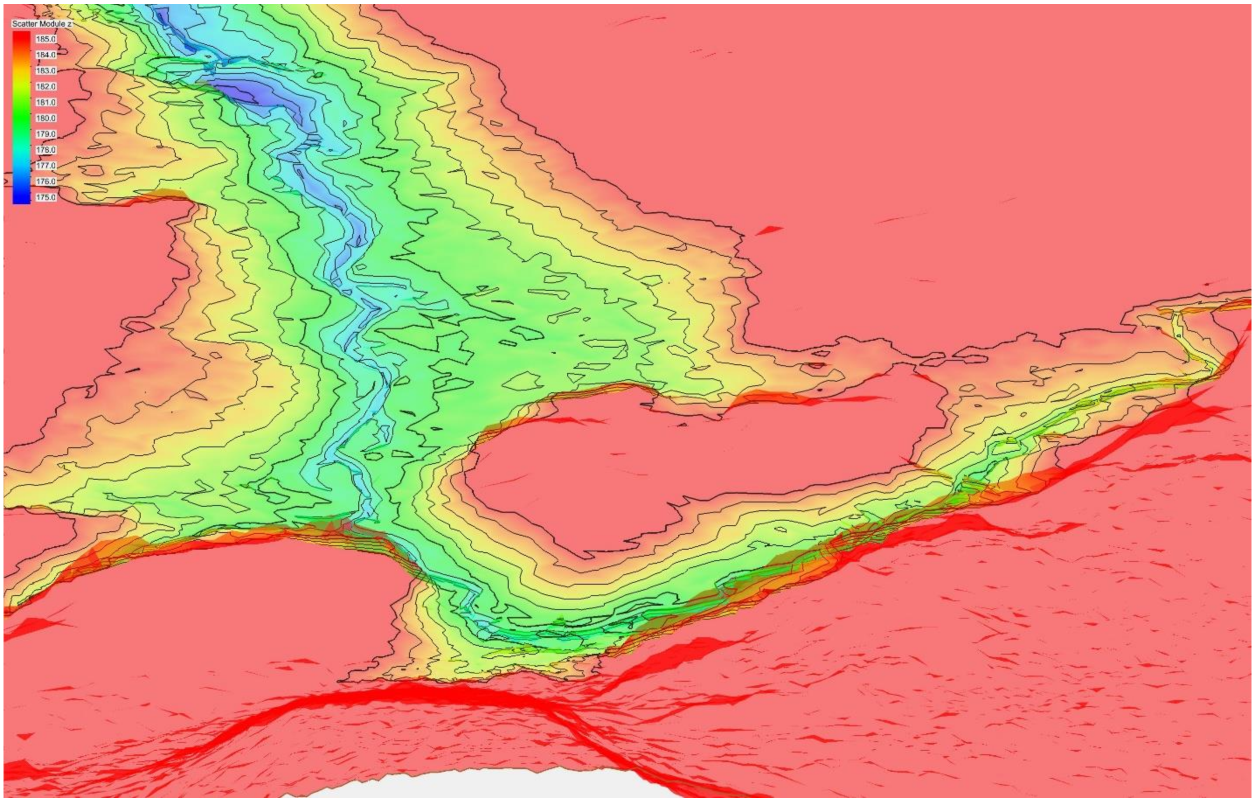

Figure 3: 3D view of existing terrain model

The developed mesh has 29,059 elements and covers 101.4 acres. The mesh density is variable, with spacings of 100 feet on the outside boundaries and 5 feet down the centerline of the channel. The mesh uses triangular elements throughout. When using the built-in mesh check tools in SMS, a significant number of elements are labeled as having the mesh quality issue “Maximum slope”, but this appears to be primarily due to the terrain, not an issue with the mesh creation. A dataset calculating the difference between the mesh and the underlying elevation scatter set to check that the mesh accurately reflects the ground surface shows an excellent correlation.

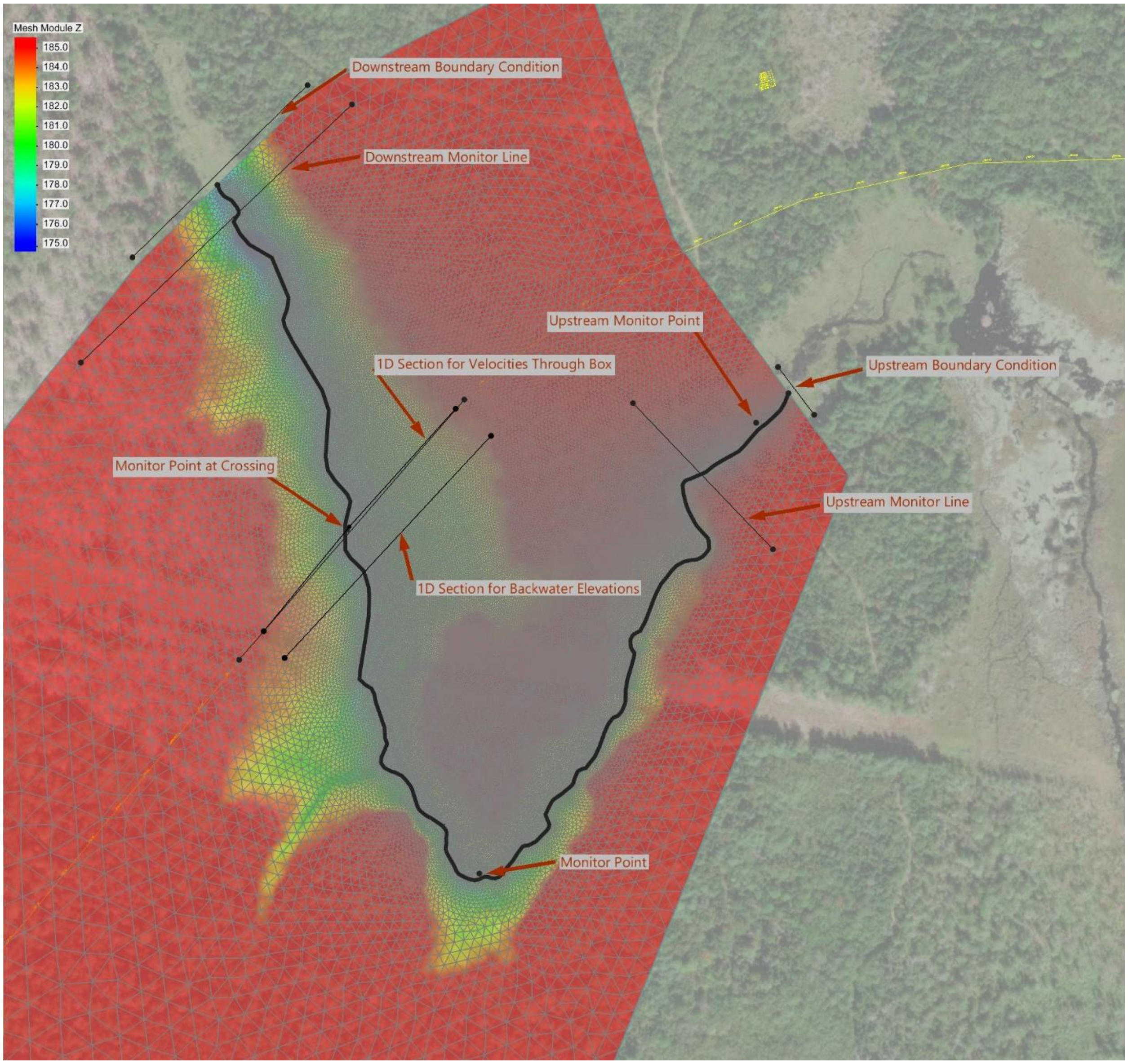

Figure 4: Existing model mesh and coverages labelled to show monitor points and 1D sections where results were checked

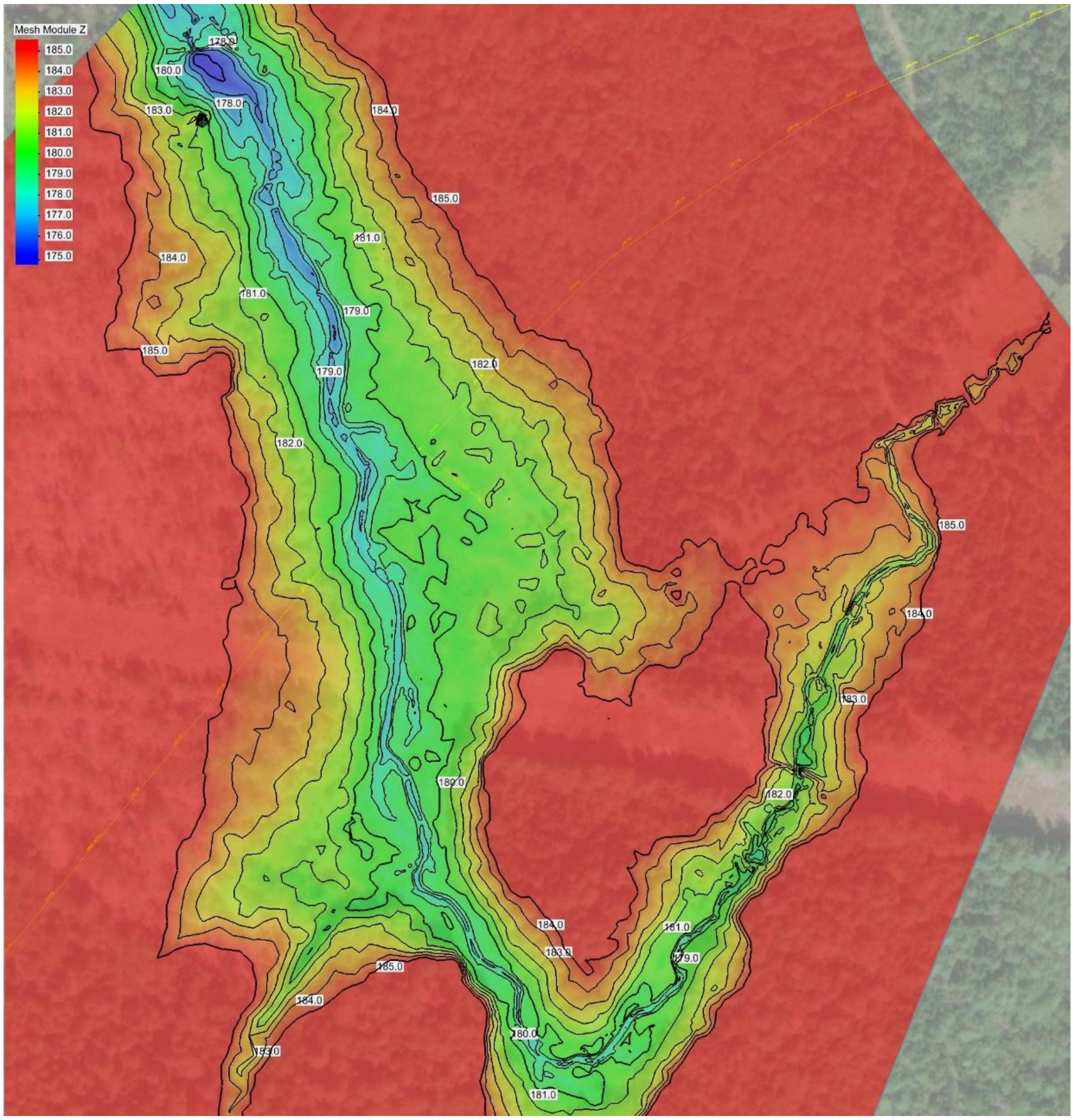

Figure 5: Existing model mesh contours showing elevations

The inflow boundary condition is an Inlet-Q (defined flow) line set at the upstream limits of the model. The exit boundary is an Exit-H (set elevation) line. The downstream water elevation was estimated using the built-in tool in SMS. For this model, the downstream values used were 0.6 for the composite Manning's n and 0.001 for the stream slope. The stream slope was estimated by measuring in the LiDAR data the change in elevation of the stream bank downstream of the model boundary. To evaluate whether the model was sensitive to changes in the downstream boundary condition, the Q100 flow was run with the downstream boundary elevation varied by ±0.5 feet. The change in water elevation at the proposed structure location was about <1 inch in magnitude for both cases, which would normally indicate a low sensitivity.

However, the magnitude of the change was much larger for the boundary elevation being raised 0.5 feet, so two additional cases were checked, with the boundary condition raised by 1.0 and 2.0 feet. These resulted in Q100 flood elevation changes of approximately 3 inches and 4.5 inches at the structure. So, the initial downstream boundary condition seems to match the normal slope well, but the model is somewhat sensitive to raises in the downstream boundary condition. This means that grade control features not included in the mesh (including temporary features, such as beaver dams) could affect flood elevations at the structure. Since the range of likely elevation change is less than 0.5 feet, this is unlikely to affect the structure design, but will be considered in the conclusions.

The model uses a Manning's n in the channel of 0.05, 0.14 for forested areas, and 0.06 for tall grass in the floodplain. The model's sensitivity to changes in the roughness was tested by running the Q100 flow and boundary condition multiple times with a single roughness value adjusted up or down by 0.005 each time. All changes to water elevations were less than 1 inch in magnitude at the proposed structure location, so the model is not sensitive to changes in roughness.

Figure 6: Roughness assignments for the existing model

No data was available for calibration except checking flooding limits against where they would be expected based on the terrain and vegetation type. Initially, the model was not flooding the area expected, even at high flows. After checking multiple possible reasons why that might be an issue, the flows were adjusted as described in the hydrology section and areas with tall grass were resurveyed because it appeared the flown photogrammetry had not detected the ground properly. Once these adjustments were made, the flooding extents at Q10 were much closer to the expected limits. The flooded area is still smaller than expected based on field observations of the vegetation, but after checking the sensitivity of the model to various factors, it seemed likely that the difference in elevation was due to physical features not picked up in the survey, like additional grade controls, not to the assumptions used in the modeling. The additional data needed to calibrate the model accurately past this point would have been time consuming to collect and any changes in grade control were likely to decrease the difference between the existing and proposed models, so the model was determined by engineering judgment to be sufficient for design. The results will be considered with the caveats that actual floodplain inundation may be higher and wider than is modeled and that a larger margin of error than usual needs to be considered.

To check whether the run time was long enough, the flows through the monitor lines were checked to see how closely the values converged. For the existing mesh with a time step of 5 seconds, the run times varied from about 4 hours to convergence for the Q1.1 flow to 2 hours to convergence for the Q100 flow.

However, when the proposed mesh was run with a 5 second time step, there were noticeable oscillations in the results, so the timestep was reduced to 2 seconds, which improved the model stability. In the proposed model, larger flows required longer run times to reach equilibrium, with the Q100 flow needing 5 hours to converge. Since the data comparison tool in SMS need to have the model steps match up, the existing model was rerun with a time step of 2 seconds to match the proposed model.

Once the existing model had been tested for sensitivity and calibration, a proposed model terrain was created by importing the proposed roadway embankment surface from CADD and converting it to a point elevation set. The built in Feature Stamping tool in SMS was used to cut the box layout for both the stream culvert and the wildlife crossings in the floodplain through the roadway embankment, then the point elevation sets were combined to create the proposed model terrain. The mesh definition was adjusted by adding lines along the roadway embankment to ensure the mesh would break smoothly at those points and accurately represent elevations, and rectangular elements were defined through the culvert.

The material roughness assignments were adjusted so that the roadway embankment was defined as cleared grassy area with a Manning's n of 0.03. Since the flood elevations will not reach the top of the roadway embankment, a separate material was not defined for the pavement surface.

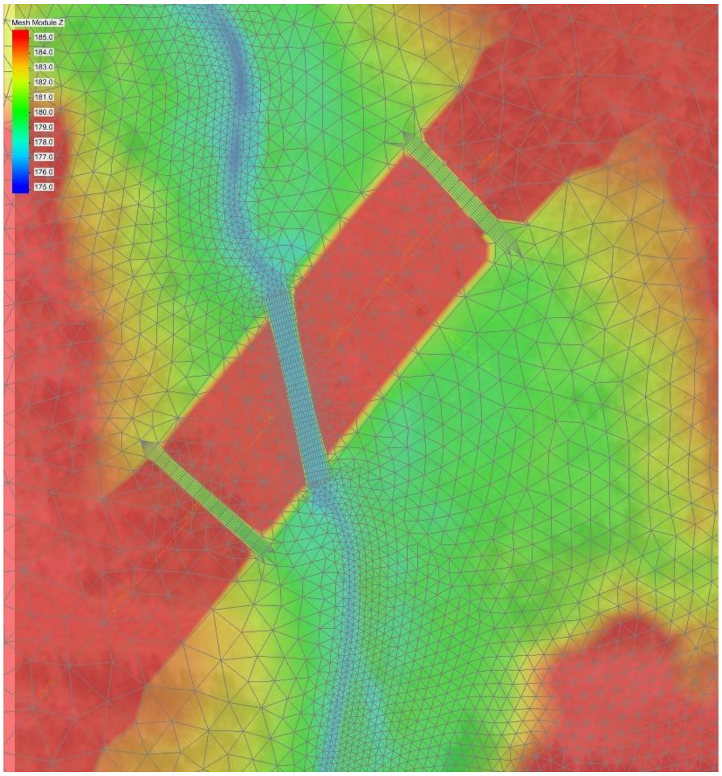

Figure 7: Detailed view of mesh at the bridge for the proposed condition with color assigned by elevation

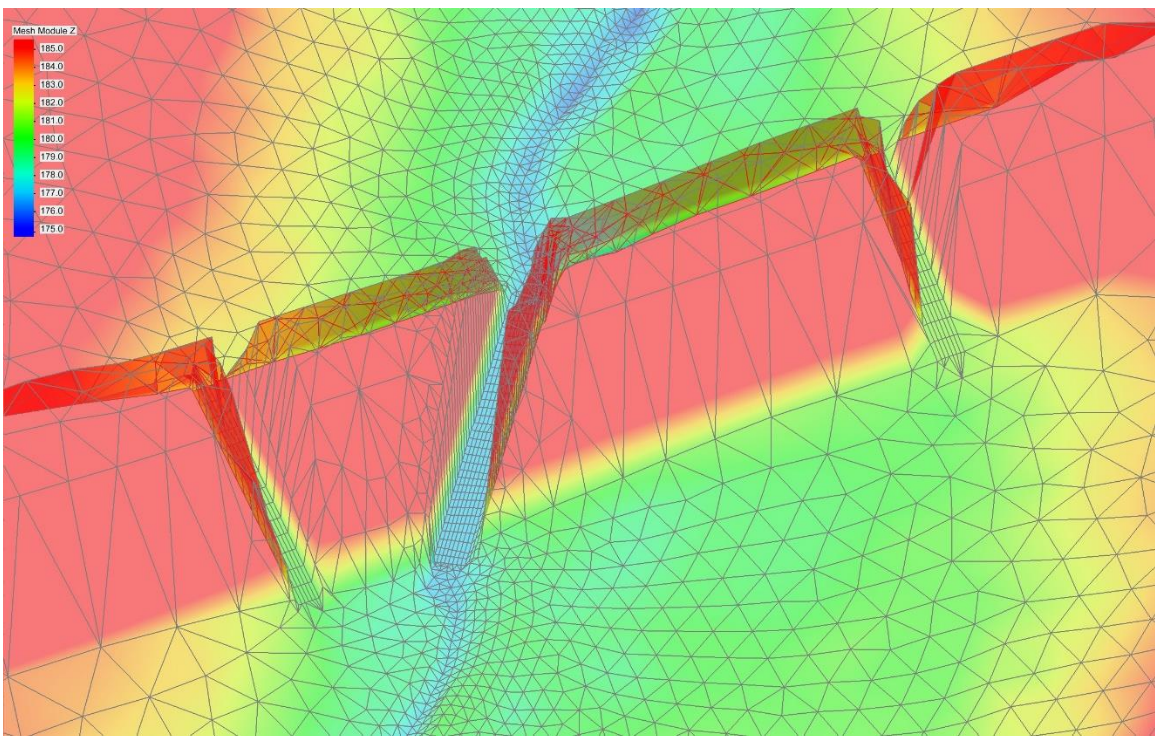

Figure 8: 3D view of proposed model mesh at bridge

Figure 9: Roughness assignments for the proposed model

Hydraulic Analysis Results for Existing Conditions

The existing model gives an elevation of just over 180 feet for the Q100 flood elevation at the proposed culvert location, with velocities a little under 2 feet per second in parts of the channel and less than 1 foot per second in the floodplain. Q1.1 results are an elevation just over 179 feet with velocities less than 1 foot per second.

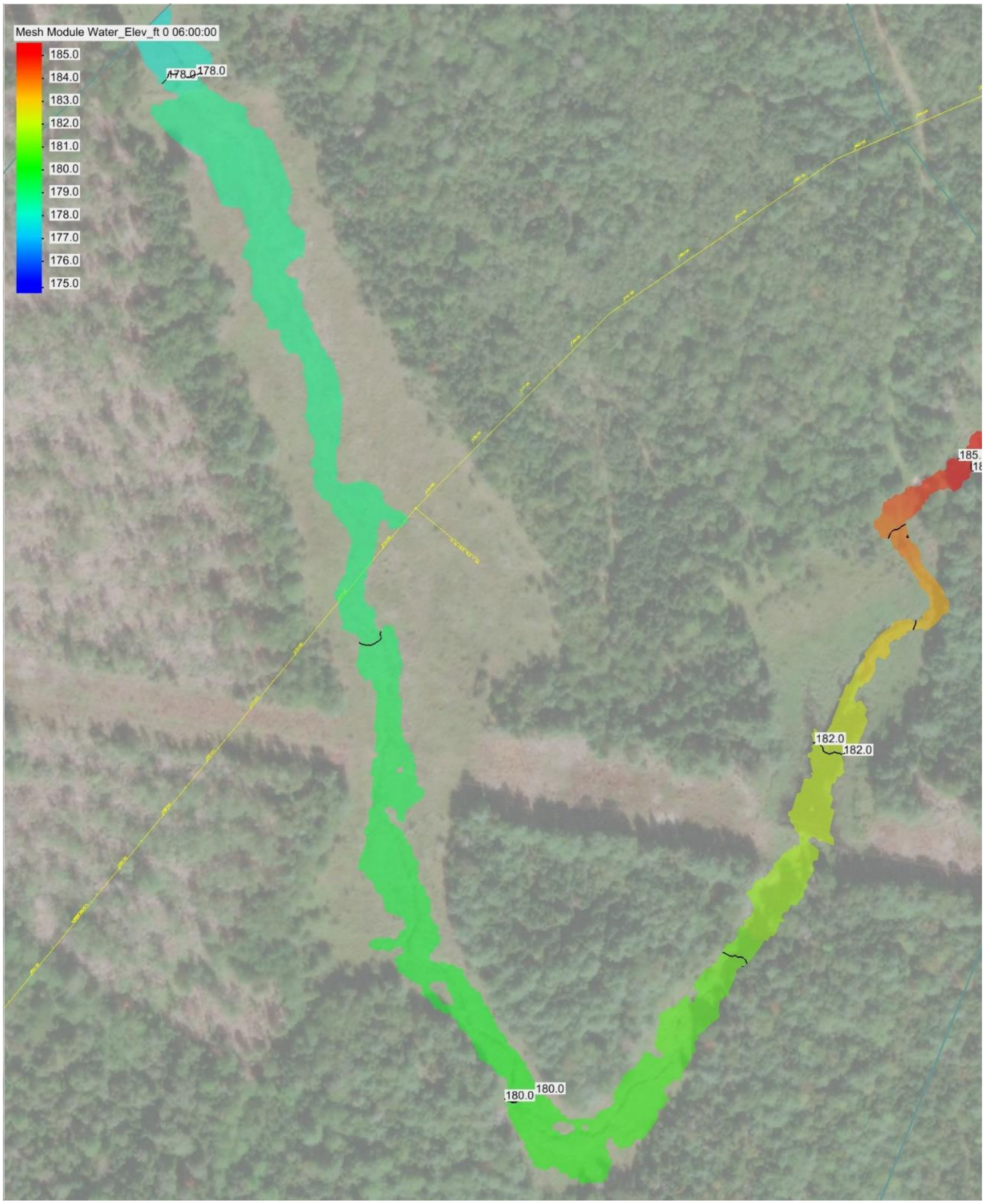

Figure 10: Existing Q1.1 Water Surface Elevations

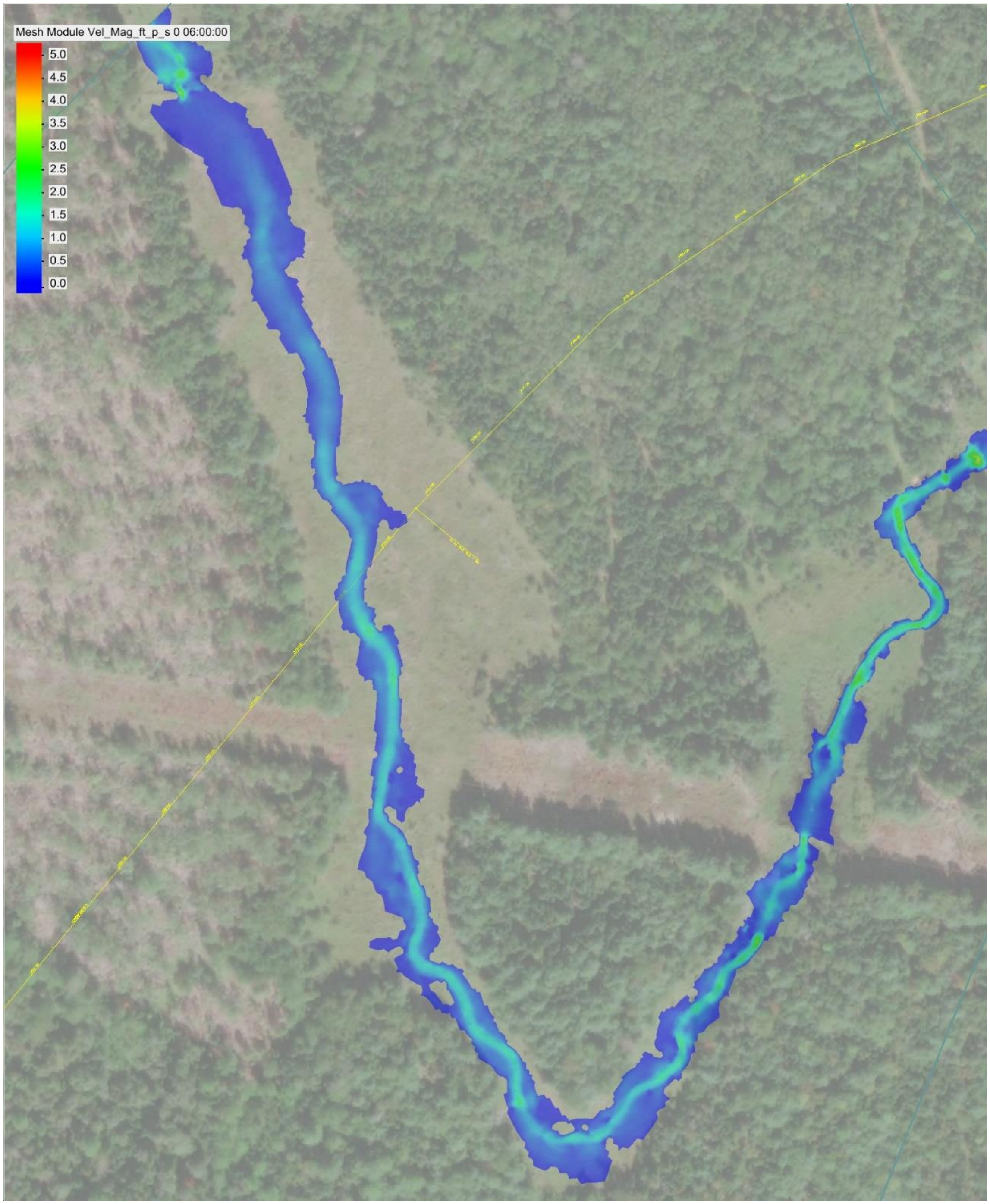

Figure 11: Existing Q1.1 Velocities

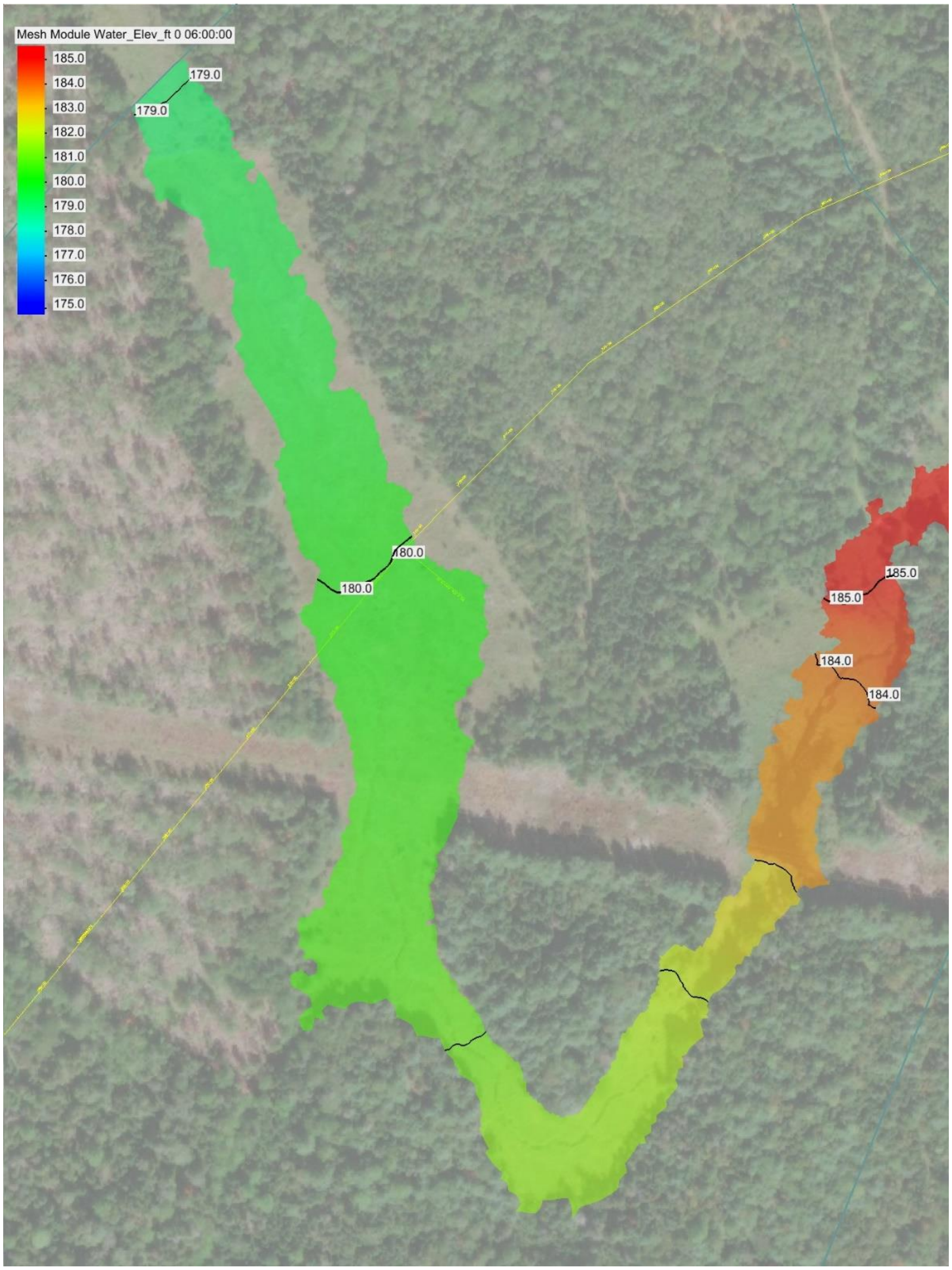

Figure 12: Existing Q100 Water Surface Elevations

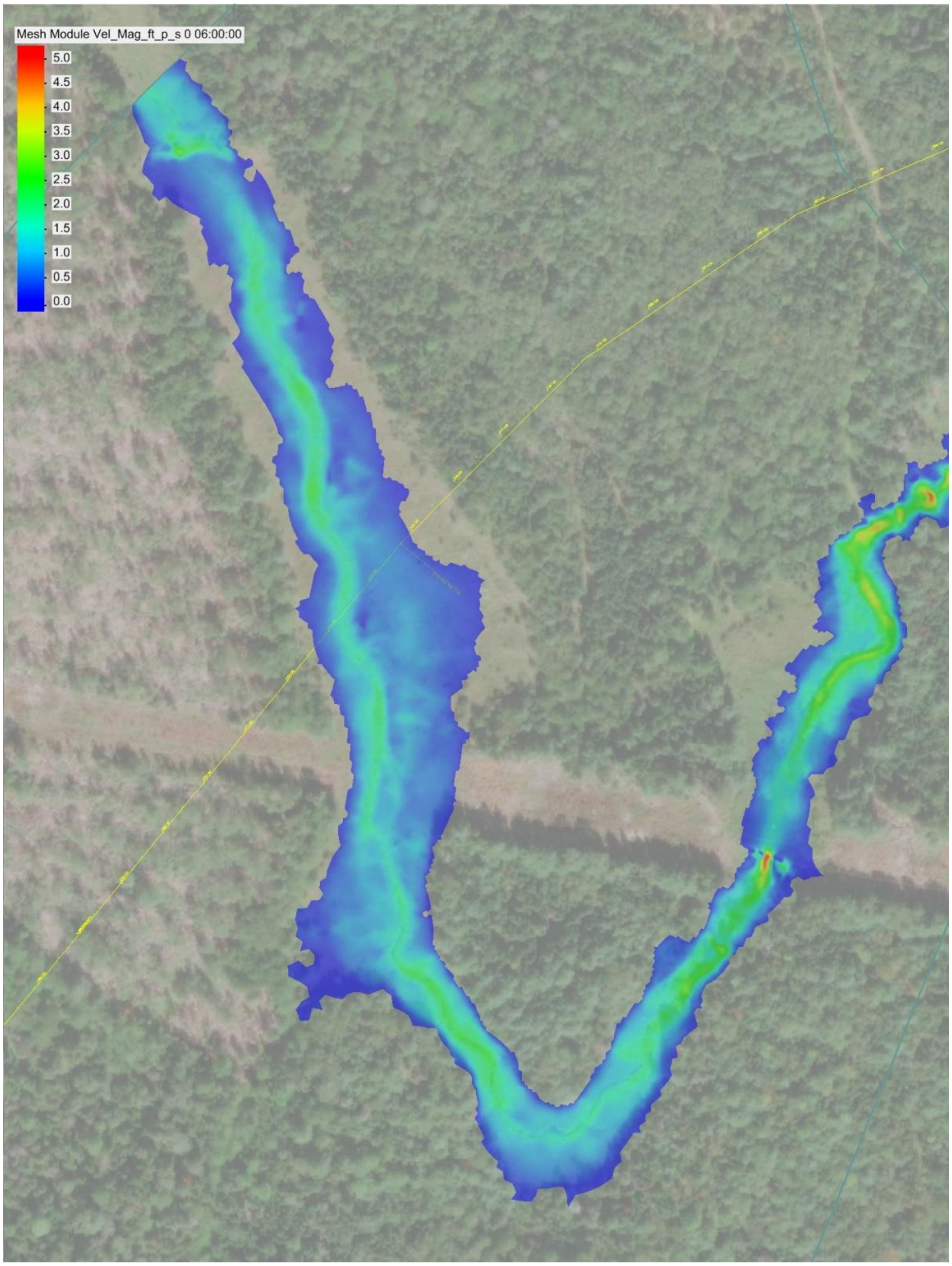

Figure 13: Existing Q100 Velocities

Hydraulic Analysis Results for Proposed Conditions

The proposed model shows a backwater condition for the Q100 flow, with an elevation of 180.5 feet. Stream velocities were not substantially changed from the existing condition, but the culvert exit velocity increased to a little over 3 feet per second.

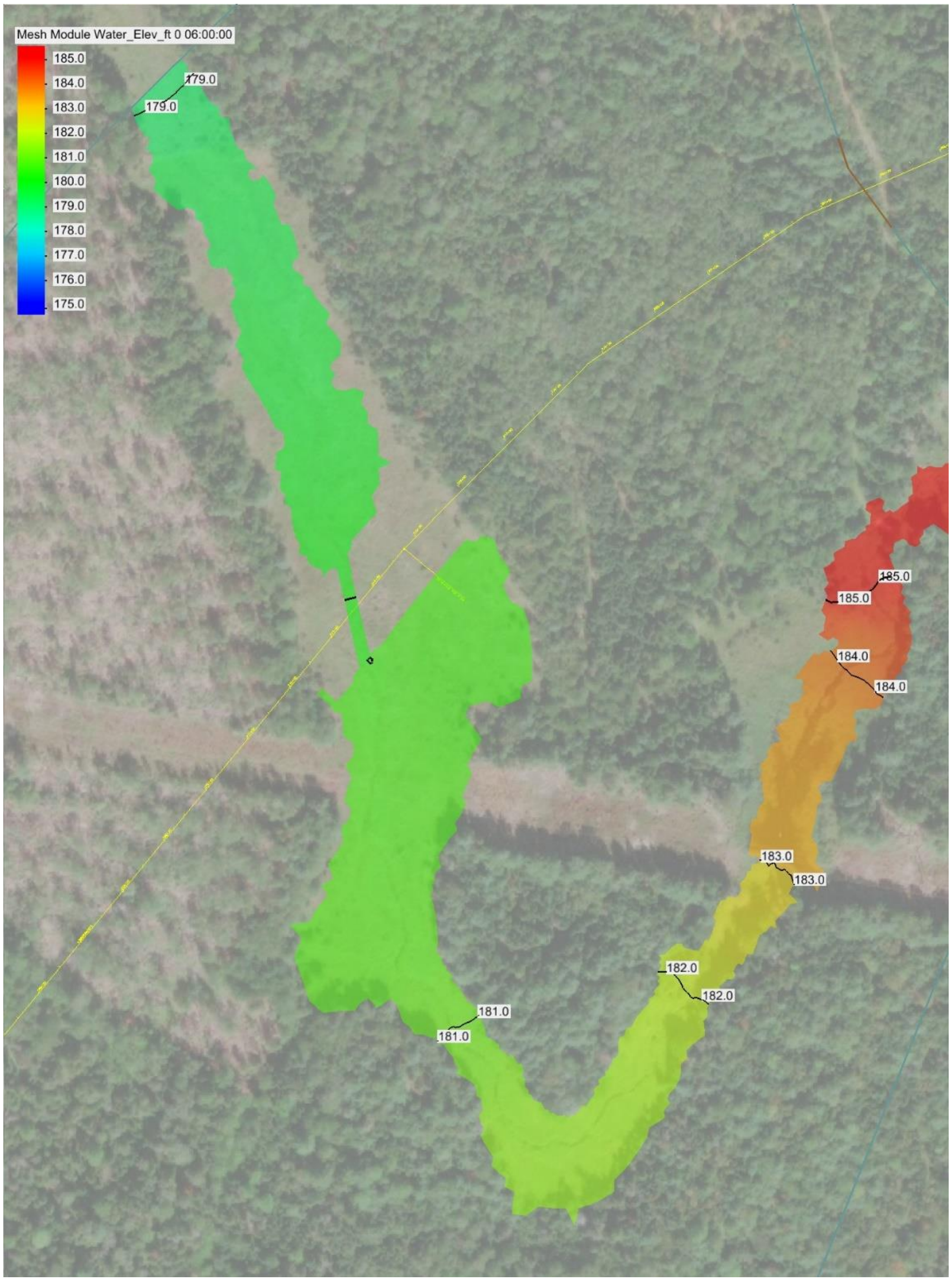

Figure 14: Proposed Q100 Water Surface Elevations

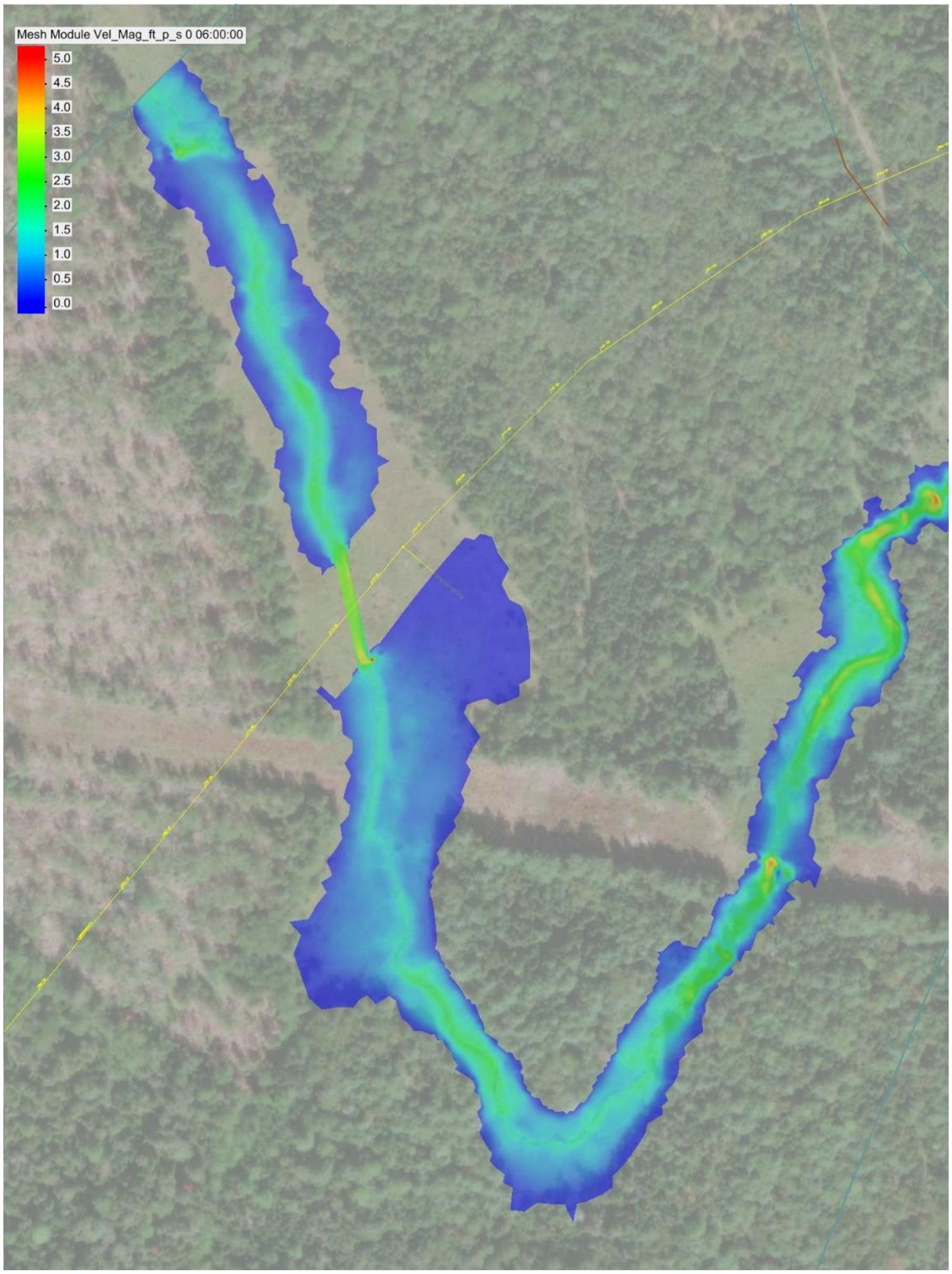

Figure 15: Proposed Q100 Velocities

The best way to evaluate the changes caused by the proposed culvert is a comparison between the proposed and existing models. Images are shown for Q1.1 and Q100 comparisons, where green values show the proposed is essentially the same as existing, blue areas are where the proposed model blocked off flow, and red areas are additional areas flooded by the proposed model. For water elevations, the range was set at plus or minus 1 foot, and for velocities the range is plus or minus 5 feet.

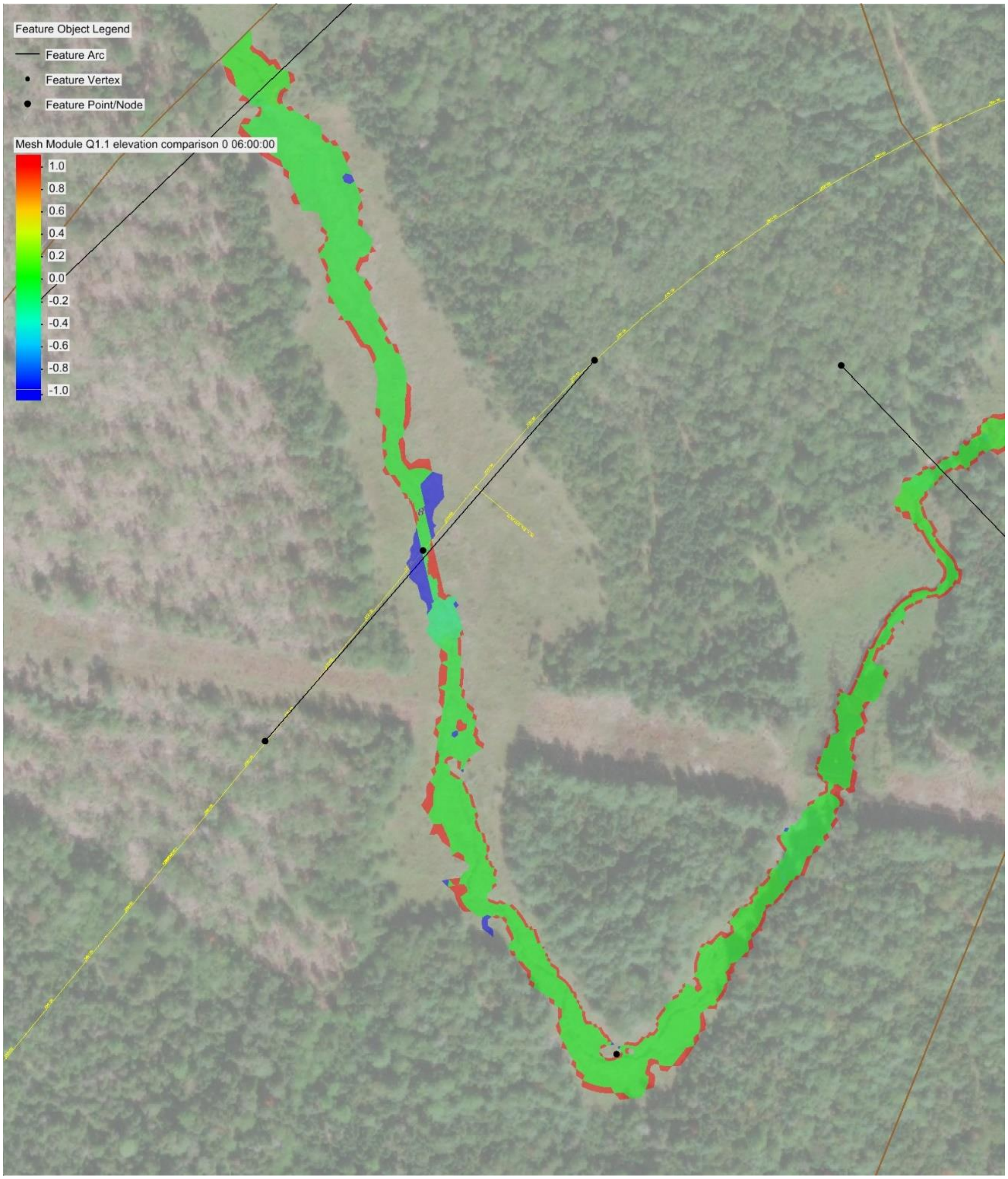

Figure 16: Q1.1 Change in Water Surface Elevation from Existing to Proposed

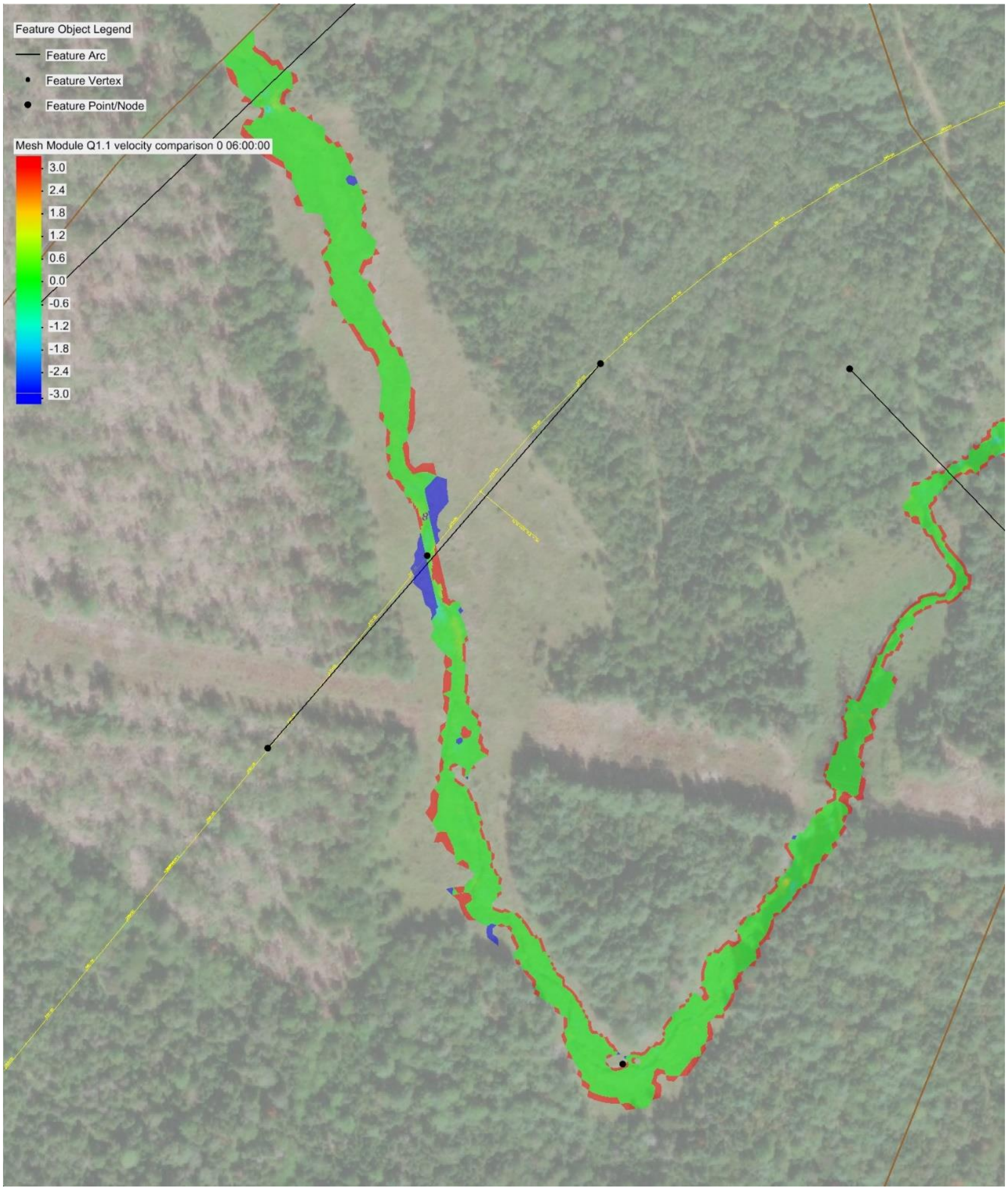

Figure 17: Q1.1 Change in Velocity from Existing to Proposed

Changes in elevation and velocity are low for the Q1.1 results, with the backwater elevation and outlet velocity actually showing lower by minor amounts, likely due to the straightening of the channel through the box. Changes are measurable but within reasonable range for the Q100 results, with the backwater elevation raised by about 0.3 feet, and outlet velocities through the end of the box by 1.5 feet per second.

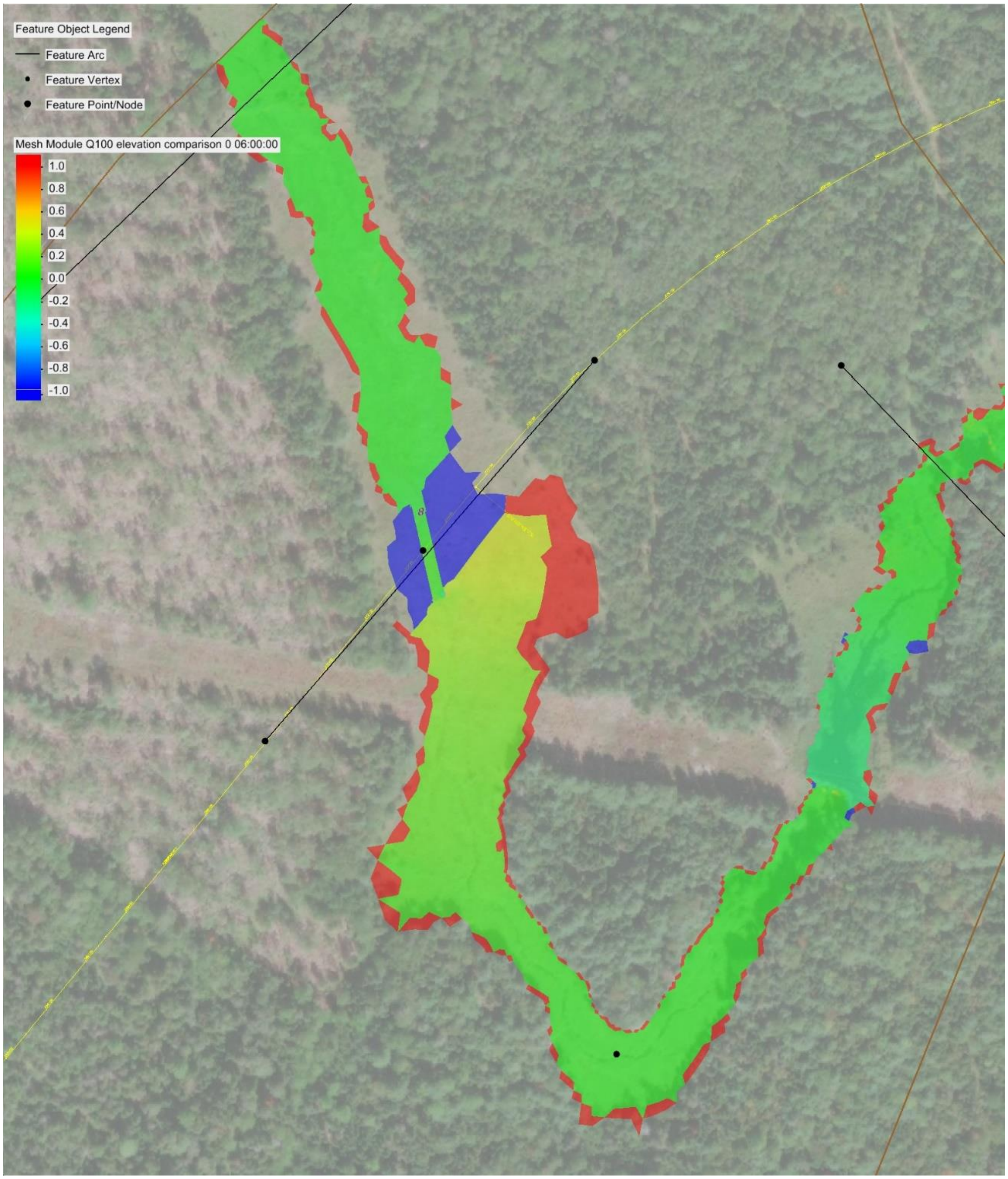

Figure 18: Q100 Change in Water Surface Elevation from Existing to Proposed

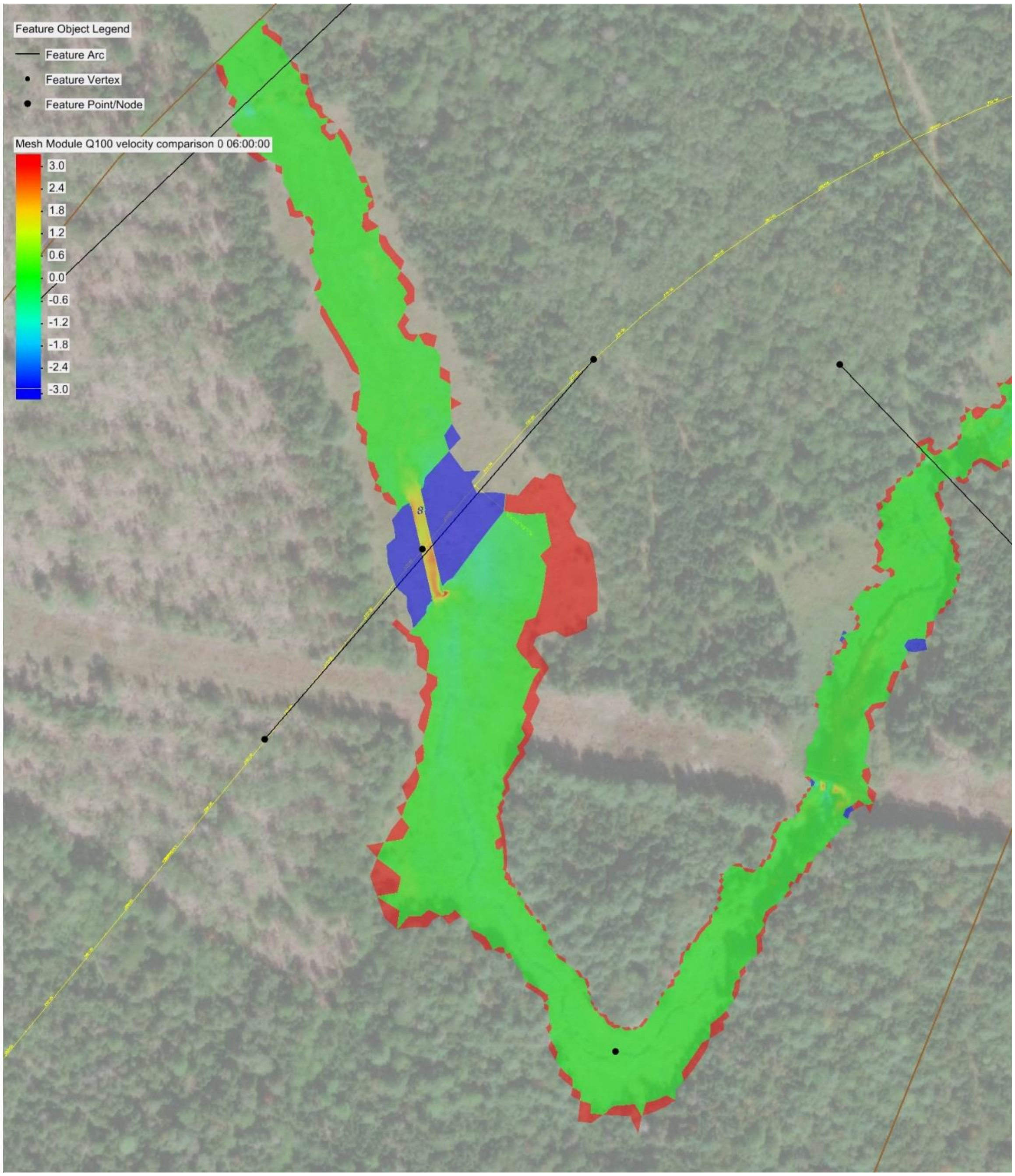

Figure 19: Q100 Change in Velocity from Existing to Proposed

Stream Stability and Scour Evaluation

The Q1.1 velocities present should not present any risk for scour. Velocities at higher flood show a minor scour risk within the box. To protect against scour, the inlet, outlet, and bottom layer of the fill in the box should be stabilized with plain riprap.

Environmental Considerations

No species specific velocity requirements are present on this project. Bank-full widths and bank requirements were determined as part of the EIS prepared by MaineDOT and FHWA for this project. The specified BFW is 12 feet.

Conclusion

The performance of the culvert is evaluated on the four criteria given in the project summary:

1. The proposed Q1.1 elevation, flooding extent, and velocity match the existing results very closely.
2. The change in headwater elevation is well less than 1 foot for the Q100 flow. There is a change in flooding extent just upstream of the culvert, but it will be closely contained by the contours at the treeline and not affect any property.
3. Q100 flow change in velocity is only 1.5 feet per second through the box, and less than that up and downstream of the box. No scour risk should be present away from the box itself.
4. The headwater to depth ratio is far below the requirement and poses no risk.

Since all the required criteria are met easily, the primary risk at this site is the discrepancy that is mentioned in the calibration section between the expected flood limits and the modeled limits for the existing condition. Based on that, the actual flood elevations and limits could be higher than is shown in the model. To mitigate that risk, the culvert size was changed from the BFW of 12 feet to 16 feet wide. Based on an evaluation of the stream channel in the survey data and the hydraulic modeling, this better matches the width needed to carry the flow from the entire floodplain through one central culvert structure with some additional capacity to compensate for the model's limitations.

Summary of Results

		Existing	Proposed Structure
		No Bridge	16' Span Box Culvert
Total Area of Waterway Opening	ft^2	N/A	128
Headwater elevation @ $Q_{1.1}$	ft	179.0	178.8
Headwater elevation @ Q_{10}	ft	179.8	179.8
Headwater elevation @ Q_{25}	ft	180.0	180.1
Headwater elevation @ Q_{50}	ft	180.1	180.3
Headwater elevation @ Q_{100}	ft	180.2	180.5
Headwater elevation @ Q_{500}	ft	180.4	180.8
Hw/D Ratio @ Q_{100}	ft	N/A	0.4
Hw/D Ratio @ Q_{500}	ft	N/A	0.5
Outlet Velocity @ $Q_{1.1}$	ft/s	1.3	1.0
Outlet Velocity @ Q_{10}	ft/s	1.8	2.2
Outlet Velocity @ Q_{25}	ft/s	1.7	2.7
Outlet Velocity @ Q_{50}	ft/s	1.7	2.9
Outlet Velocity @ Q_{100}	ft/s	1.7	3.2
Outlet Velocity @ Q_{500}	ft/s	1.7	3.8

Reported by: Joshua Hasbrouck
Date: September 4, 2020

Note: All elevations based on North American Vertical Datum (NAVD) of 1988.