HYDROLOGY REPORT

The Cousins River Bridge (#2183) is located over the town line between Yarmouth and Freeport and carries US Route 1 over the Cousins River. Upstream of the Cousins River there is a confluence where the Pratt River and "Upstream" Cousins river meet. The watershed of the Pratt River and Upstream Cousins River are approximately 10.8 mi^2 and 7.7 mi^2, respectively. As part of this study, the Royal River, found at the outlet of the Cousins River was also included which has a watershed area of 140 mi^2.

The Maine Department of Transportation (MaineDOT) Environmental Office, Hydrology Section, provided the drainage basin characteristics and flow data for this crossing. The original flow data are based on peak flow calculations using United States Geological Survey (USGS) Regression Equations that are utilized in *StreamStats (Version 4.0)* online application. As an independent check, *StreamStats (Version 3.0)* online application which utilized an older set of Regression Equations were evaluated. The peaks flows determined from *StreamStats Version 3.0* were used for this study and are summarized below.

On October 10, 2017, a site visit was performed to measure velocity and water surface elevations at the Cousins River Bridge which would be used to calibrate the hydraulic model. As part of the unsteady analysis, specifically Case 1 found in section 2.3.10.2 of the MaineDOT Bridge Design Guide, the upstream boundary conditions are to be a Constant Q1.1 or a lower more typical flow. Based on this guidance, *StreamStats* was used to determine the October Flow Statistics for the Pratt, Upstream Cousins, and Royal River and are summarized below.

The nearby station in Portland, ME (8418150) collects daily water levels at 6-minute intervals. The water levels (NAVD88) at the Portland station were increased by approximately 0.12-ft to account for the geoid and reflect the water levels at the mouth of the Cousins and Royal River at Yarmouth and Freeport.

SUMMARY OF CALCULATED PEAK FLOWS

	Pratt River		US Cousins River		Royal River	
Q2	405	ft^3/s	291	ft^3/s	2630	ft^3/s
Q10	827	ft^3/s	600	ft^3/s	4630	ft^3/s
Q25	1070	ft^3/s	782	ft^3/s	5690	ft^3/s
Q50	1270	ft^3/s	927	ft^3/s	6500	ft^3/s
Q100	1480	ft^3/s	1080	ft^3/s	7360	ft^3/s
Q500	2010	ft^3/s	1470	ft^3/s	9410	ft^3/s

SUMMARY OF CALCULATED OCTOBER FLOWS

	Pratt River		US Cousins River		Royal River	
OCTD1	1	ft^3/s	<1	ft^3/s	12	ft^3/s
OCTD10	1	ft^3/s	<1	ft^3/s	21	ft^3/s
OCTD25	2	ft^3/s	1	ft^3/s	39	ft^3/s
OCTD50	5	ft^3/s	4	ft^3/s	75	ft^3/s
OCTD75	15	ft^3/s	11	ft^3/s	182	ft^3/s
OCTD90	38	ft^3/s	28	ft^3/s	398	ft^3/s
OCTD95	70	ft^3/s	53	ft^3/s	641	ft^3/s
OCTD99	191	ft^3/s	150	ft^3/s	1540	ft^3/s

Reported by: Jeff DeGraff
Date: March 8, 2018

Hydraulic Modeling:

The existing bridge and proposed structure were analyzed using United States Bureau of Reclamation's (USBR) Sediment and River Hydraulics – Two Dimensional (SRH-2D) model. Aquaveo's Surface-water Modeling System (SMS) version 12.2 was utilized to develop the mesh and input (boundary conditions, material properties, etc.) needed to run the SRH-2D models. The hydraulic models were developed using a combination of as-built plans, topographic survey, LiDAR, NOAA bathymetric data and other available information.

The existing conditions SRH-2D model was calibrated based on the field measurements taken on October 10, 2017. The measurements included velocity and water surface elevations at the Cousins River Bridge. The calibration included adjusting manning's values, time step, and mesh size/type. Initially a time step of 10 seconds was used which provided a "coarse" solution and in some cases, the model crashed. Subsequently, a time step of 5 seconds was used which provided adequate results as compared to the measured. To test the sensitivity of the model and to establish that a time step of 5 seconds was adequate, a smaller time step of 1 second was used. The solution of a 1 second time step model was not significantly different than the 5 second time step model. This suggests that the model's errors are small between a time step of 1 and 5 seconds and is converging to a similar solution. Also, this sensitivity analysis demonstrates that the mesh size/type used throughout the domain is adequate for subsequent analyses.

A detailed summary of the Existing and Proposed Hydraulic Analysis can be found in Appendix E.

The following assumptions were used for modeling the proposed structure:

- A sea level rise was considered for unsteady flow cases 2 and 3. Sea level rise was not considered for scour analysis. Supporting hydraulic documentation uses 2 feet SLR as a representative number for the majority of the bridge service life. This summary report uses 4 feet as the DSLR in accordance with the Bridge Design Guide.
- A single span structure with approximately 107.6' clear between abutment faces
- Low chord elevation of 7.9 feet.
- Streambed at/within the structure reflects the proposed channel
- Streambed at all other areas remains the same
    - No filling or modifications to the bed downstream or upstream of the project limits.

- Manning's n values were adjusted to reflect proposed stone fill limits. See summary of Existing and Proposed Hydraulic Analysis in Appendix E.

A summary of cases run for this analysis are shown below. The existing conditions model was run for Steady flow Case 2 and Steady flow Case 2 @ Q100 to show that minimal impacts result from the proposed conditions.

SUMMARY OF BOUNDARY CONDITIONS

Case	**Upstream Boundary**	**Downstream Boundary**	**Site Conditions (*Existing or Proposed*)**
Steady flow Case 1	Constant 50-year peak flow (all rivers)	MHW	*Proposed*
Steady flow Case 2	Constant 50-year peak flow (all rivers)	MLW	*Existing and Proposed*
Steady flow Case 2 @ 100yr	Constant 100-year peak flow (all rivers)	MLW (without sea level rise)	*Existing and Proposed*
Steady flow Case 2 @ 500yr	Constant 500-year peak flow (all rivers)	MLW (without sea level rise)	*Proposed*
Unsteady flow Case 1	Pratt – OCTD50 US Cousins – OCTD50 Royal – OCTD90 *(all flows are constant)*	October 10, 2017 Tide	*Existing and Proposed*
Unsteady flow Case 2	Constant 50-year peak flow (all rivers)	Typical Tide based on mean tide with sea level rise	*Proposed*
Unsteady flow Case 3	Pratt – OCTD50 US Cousins – OCTD50 Royal – OCTD90	100-year surge with sea level rise	*Proposed*

The SRH-2D results for the existing conditions and proposed conditions are provided in Appendix E.

Scour:

The proposed countermeasures to armor the abutments are to be permanent. Therefore, Contraction Scour within the proposed channel was analyzed per FHWA Hydraulic Engineering Circular 18 – Evaluating Scour at Bridges (HEC-18), Fifth Edition, published April 2012.

The proposed hydraulic data used in the scour and riprap sizing calculations are taken from the SRH-2D model of the proposed conditions (without sea level rise). The MaineDOT Bridge Design Guide 2.3.10.2.C, Steady flow Case 2 would produce the highest velocities. Steady Flow Case 2 includes a 50-year steady flow upstream and Mean Low Water Downstream boundary conditions. The hydraulic analysis showed that this case did produce the highest velocities which in return produced the highest unit discharges. Typically, the highest unit discharges produce the largest scour depths. Per MaineDOT Bridge Design Guide Section 2.3.11.1, the design flood for scour is the lesser of Q100 or the overtopping flood. The proposed condition model indicates no overtopping at the bridge occurs for all flood events, including the 500-year flood. Therefore, the scour and riprap design calculations are completed using the 100-year flood event as the upstream boundary conditions with a Mean Low Water (MLW) surface elevation as the downstream boundary condition (Steady flow Case 2 @ 100-yr). Similarly, the 500-year flood event as an upstream boundary condition with a MLW downstream boundary conditions was used as a check (Steady flow Case 2. @ 500-yr). The scour should also be computed for the superflood, defined as Q500 or the overtopping flood if it is between Q100 and Q500, per the Bridge Design Guide.

The bed material comprises of Silty-Soils with an average median diameter of bed material (D_{50}) of the streambed estimated at approximately 0.08mm. Silty and clayey soils have cohesive properties which increase critical shear stress due to cohesion. Therefore, Shields relationship is not appropriate to use to determine critical shear stress for cohesive soils. To estimate the critical shear stress, the upper limit (equation) in Figure 6.9 of HEC-18 was used. To estimate the ultimate contraction scour at the bridge, equation 6.6 of HEC-18 was used. The ultimate scour depth during the Steady flow Case 2 @ 100-yr was determined to be 5.5'.

Riprap slopes will be provided in front of the proposed abutments, which will be located outside the river. Based on the riprap sizing calculations included in Appendix E, a 4' thick layer of heavy riprap will be required. The riprap sizing was calculated using HEC-23 – Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance, Third Edition, published in September 2009, as well as the MaineDOT Standard Specification Section 703 and MaineDOT Standard Detail sheet 610(02). Although riprap will be provided for scour protection, the design of piles supporting the abutments should consider the potential loss of the riprap. Therefore, the piles should be designed for the additional unbraced length due to scour assuming the riprap protection is not there.

SUMMARY

		Existing 50' clear span (Tee-beam)	Option 1: 111' clear span (NEBT)	Option 2: 111' clear span (Steel)
Total Area of Waterway Opening	SF	705	1081	1227
Superstructure Depth	FT	6	7.0	5.7
Low Chord Elevation	FT	7.8	7.9	9.2
Freeboard @ MHW	FT	3.03	3.57	4.87
Freeboard @ (MHW + DSLR)	FT	-0.97	-0.43	0.87
Freeboard @ HAT	FT	1.2	1.3	2.6
Storm Surge Elevation (50-year)	FT	8.60	8.60	8.60
Storm Surge Elevation (100-year)	FT	9.22	9.22	9.22
Mean Lower Low Water (MLLW)	FT	-5.14	-5.14	-5.14
Mean Low Water (MLW)	FT	-4.79	-4.79	-4.79
Mean Tide Level (MTL)	FT	-0.23	-0.23	-0.23
Mean High Water (MHW)	FT	4.33	4.33	4.33
Mean Higher High Water (MHHW)	FT	4.77	4.77	4.77
Maximum Scour Velocity (100-yr)	FPS	12.8	10.0	10.0
Average Velocity	FPS	3.0	2.0	2.0
Highest Annual Tide (HAT - 2017)	FT	6.81	6.81	6.81
Lowest Annual Tide (LAT - 2017)	FT	-7.26	-7.26	-7.26
Highest Recorded Tide (1978)	FT	8.99	8.99	8.99
Design Sea Level Rise (DSLR)	FT	N/A	4	4

Reported by: Jeff DeGraff
Date: March 12, 2017

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