

HYDROLOGY REPORT

Lewis Bridge (BR #5396) carries State Route 125 (Main Street) over the southerly flowing West Cathance Stream in Bowdoin, ME. As can be seen in Figure 1, approximately 1/3 mile west of the project is Coombs Bridge (BR #5395) over Coombs Brook. Coombs Brook flows easterly along Main Street from Coombs Bridge to a reach junction with West Cathance Stream, located approximately 300-ft downstream of Lewis Bridge. This junction is located over 1800-ft downstream of the Coombs Bridge. The nearest stream crossing downstream of Lewis Bridge is Wentworth Bridge, which is approximately 1.5 miles downstream (straight line between points not including stream meander).

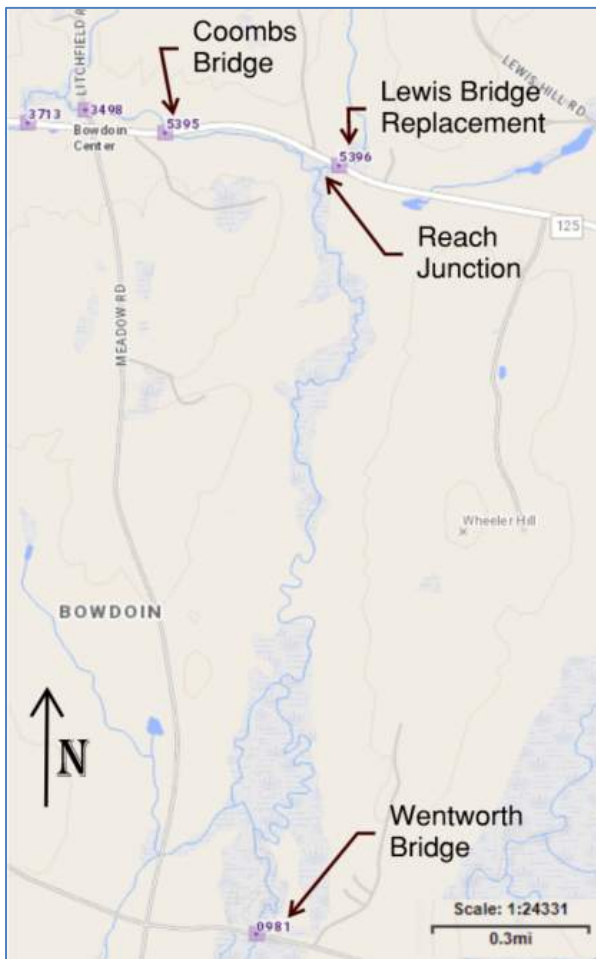


Figure 1 - Lewis Bridge Location

The watershed area for West Cathance Stream at the Lewis Bridge is 2.14 square miles with 0.1 square miles of wetlands. The watershed is rural with some private residences/businesses and is located primarily to the north of Lewis Bridge. The watershed area for Coombs Brook at the junction with West Cathance Stream is 1.65 square miles and is primarily west of the reach junction. See Figures 2 & 3 for the watershed areas. Flowrates from the hydrology reports are rounded up slightly, if appropriate, and are shown in Table 1 below.

The drainage basin characteristics for West Cathance Stream and Coombs Brook were provided by the MaineDOT Environmental Group, Hydrology Section. Peak flows were calculated with techniques described in:

- Hodgkins, G.A., 1999. "Estimating the Magnitude of Peak Flows for Streams in Maine for Selected Recurrence Intervals". United States Geological Survey (USGS) Water-Resources Investigations Report 99-4008
- Lombard, P.J. & G.A. Hodgkins, 2015. "Peak Flow Regression Equations for Small, Ungaged Streams in Maine: Comparing Map-Based to Field-Based Variables". Scientific Investigations Report (SIR) 2015-4059, USGS, Augusta, ME.
- Lombard, P.J. & G.A. Hodgkins, 2021. "Estimating Flood Magnitude and Frequency on Gaged and Ungaged Streams in Maine". SIR 2020-5092, USGS, Augusta, ME.

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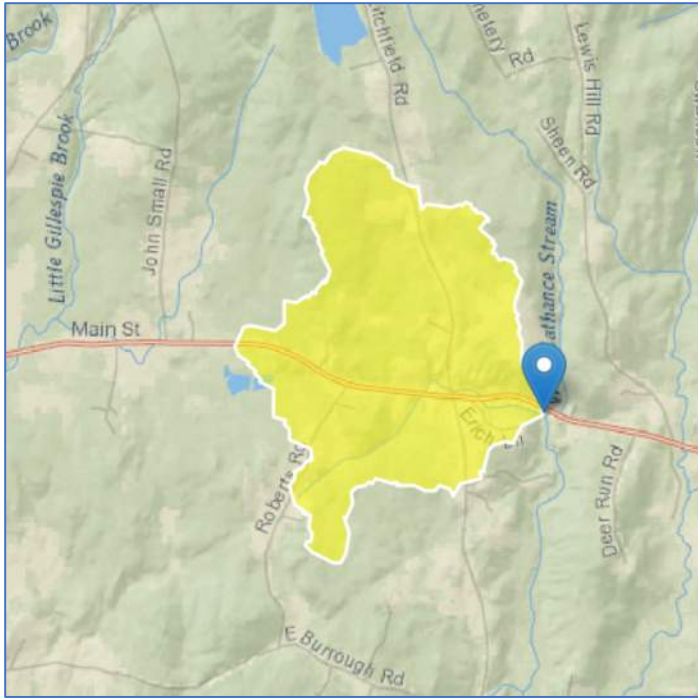


Figure 2 - Coombs Brook Watershed

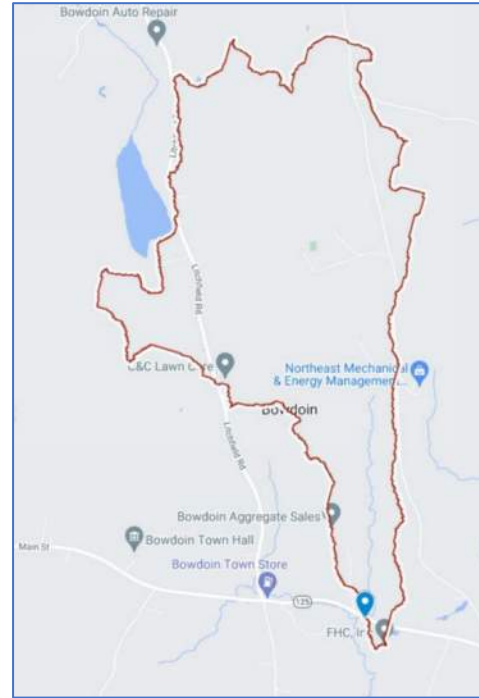


Figure 3 - West Cathance Stream Watershed

Table 1 - Design Flow Rates

<u>Annual Exceedance Probability (AEP)</u>	<u>Return Period (yr.)</u>	<u>West Cathance Stream (cu. ft/s)</u>	<u>Coombs Brook (cu. ft/s)</u>
90.9%	1.1	55	45
50%	2	120	90
20%	5	195	145
10%	10	255	190
4%	25	335	250
2%	50	400	300
1%	100	470	355
0.5%	200	545	410
0.2%	500	650	490

For West Cathance Stream, the hydrology report provides an estimated bankfull width (BFW) of 14.7-ft. An average of measurements taken by MaineDOT upstream of Lewis Bridge resulted in a design BFW of 18.2-ft. This project incorporates Habitat Connectivity Design, so the proposed structure will have a span of at least 1.2*BFW (21.8-ft). Therefore, a span of 22-ft is proposed for the new Lewis Bridge.

HYDRAULIC REPORT

FLOOD INFORMATION

The FEMA Flood Insurance Study (FIS) that covers the Town of Bowdoin, Maine was published July 16, 2015, and is a comprehensive report covering many communities in Sagadahoc County. FEMA and the Maine Flood Hazard Map indicate that both Lewis Bridge and Coombs Bridge are in a Zone A floodplain, which is a “Special Flood Hazard Area” without Base Flood Elevation (BFE). The FIS states that the Zone A limits were developed for a 1-percent-annual-chance



Figure 4 - Maine Flood Hazard Map

floodplain using approximate methods. See Figure 4.

Corroborating apparent inundation of the roadway near Lewis Bridge is information in the 10/13/2021 bridge inspection report (Section 71) for “Waterway Adequacy” with a rating of “6 – Occasional Overtopping of Approaches – Insignificant Delays”.

There is no information from abutters or town officials regarding flooding at the project site. However, Google Street View imagery shows fallen trees carried by floodwaters on top of the inlet’s west wingwall. See Figures 5 & 6.



Figure 5 - Fallen Trees on Top of Inlet Wingwall (Google Streetview image captured Sept 2016)



Figure 6 - Fallen Trees on Top of Inlet Wingwall (Google Streetview image captured Sept 2016)

DESIGN HYDRAULIC CLEARANCE REQUIREMENTS

Site observations and Google Street View imagery indicates numerous fallen trees being transported in West Cathance Stream during high flows. Fallen trees with diameters of up to 12” to 14” were observed within the stream channel, spanning the channel, and along the streambanks. (See Figures 7 to 9).



Figure 7 – Fallen Trees Across West Cathance Stream Channel (looking downstream toward stream junction)



Figure 8 - Fallen Trees Across and Within West Cathance Stream Channel (looking upstream from stream junction)



Figure 9 - Fallen Trees in West Cathance Stream Channel (looking upstream at stream junction)

Per MaineDOT's Bridge Design Guide, the hydraulic clearance requirement for the headwater to depth ratio (HW/D) for a new culvert is 0.9 or less for Q50. Since this project incorporates Habitat Connectivity Design (HCD), there is an additional requirement that $HW/D \leq 1.0$ for Q100. Given the site observations, even with these hydraulic clearance criteria, post-flood maintenance activities are still likely for debris/fallen tree removal from the culvert inlet.

HYDRAULIC MODELING

The hydraulic analysis was developed using HEC-RAS 6.3.1 (September 2022) a one-dimensional hydraulics software program developed by the United States Army Corps of Engineers Hydrologic Engineering Center. It includes an existing conditions model that was developed and tested for its sensitivity to Manning's N and normal depth assumptions, and then evaluated against known data for reasonableness. It also includes a proposed conditions model that was developed from the existing conditions model to represent the expected hydraulic conditions after project construction. Due to the highly mobile nature of the fine streambed materials, no other post-project models were developed since the streambed materials are expected to be transported at most flows.

The model's geometry was developed using ground survey obtained in May/June 2022 and aerial Lidar data with 1-ft contours, both provided by MaineDOT. The model includes 7 cross sections upstream of Lewis Bridge, 10 cross sections between Lewis Bridge and the junction with Coombs Brook, 4 cross sections on Coombs Brook, and 8 more downstream of the junction.

Ground survey contained data for two small beaver dams spanning the channel upstream of Lewis Bridge near reach station (RS) 303+83 (Beaver Dam 1) and RS 304+87 (Beaver Dam 2). Beaver Dam 1 is closest to Lewis Bridge and was partially washed out with dam remnants occupying slightly more than 1/2 the channel width on the left side of the river (instead of the full channel width shown in the survey file and Inspection Report photos). Beaver Dam 2 was in relatively poor condition. Large key logs were not visible and the dam looked old. There was no evidence of recent beaver activity (newly harvested branches, felled trees, or stumps), so both dams are expected to continue deteriorating unless beaver activity resumes to rebuild them. Based on likely continued deterioration, and since the beaver dams are upstream of Lewis Bridge, they were not included in the hydraulic model.



Figure 10 - Looking Upstream at Beaver Dam 2



Figure 11 - Beaver Dam 2 in Poor Condition w Low Stability

As can be seen in Figure 10, there is an 8.5-ft wide square outbuilding on the bank of the stream adjacent to Beaver Dam 2. Due to its relatively small size in comparison to the FEMA Zone A floodplain area, the effects from this outbuilding were not considered in the hydraulic model. A private residence located approximately 180-ft north of Lewis Bridge was also excluded from the model since it is outside the FEMA Zone A floodplain area, and its lowest surveyed elevation is El. 136.63, which is nearly 9-ft higher than the existing Lewis Bridge top of curb/headwall.

The geometry of the existing reinforced concrete box culvert inlet and outlet were measured to have a 10'-0" span and a 4'-0" rise. No culvert invert elevations were provided in the ground survey file, so field measurements were used in conjunction with surveyed top of curb elevations to determine the existing invert elevations. The proposed box culvert span and inverts were determined using habitat connectivity design. See the separate Habitat Connectivity Design Report for more information.

Both hydraulic models were generated by modeling the existing and proposed structures as bridges to allow increased flexibility in modeling the variable depth streambed materials placed within the proposed box culvert for the channel and channel margins.

The following parameters were established/assumed for the hydraulic models:

- Steady flow analysis method.
- Manning’s “n” of 0.052 for the channel, which is comprised of mostly silt, sand, and clay.
- Manning’s “n” of 0.099 for the overbank areas for brush and trees.
- Manning’s “n” of 0.017 for the existing reinforced concrete box culvert.
- Expansion and contraction values of 0.3 and 0.1, respectively, except for the two reach cross sections immediately upstream of Lewis Bridge and one cross section immediately downstream of Lewis Bridge, which used 0.5 and 0.3, respectively.
- Ineffective flow areas were set with a contraction ratio of approximately 1:1 upstream of the structure, and an expansion ratio of approximately 2:1 on the downstream side, taking into account topography and stream meander.
- Subcritical flow regime.
- Boundary conditions at the downstream limit were set to “normal depth”, with the slope based on the approximate average stream slope.

A sensitivity analysis determined that the model was not very sensitive to the Manning’s N and normal depth slope assumptions.

HYDRAULIC RESULTS

Existing Conditions Model

Since there is no base flood elevation (BFE) or gage data at this site, the existing conditions model was evaluated against site measurements/observations and available information to verify that the results appear reasonable.

1. No obvious high-water marks were visible on the culvert or its wingwalls, so the next best available information were water depth measurements from the site visit. While the flow rate was unknown, it appeared low, and the water depths were measured to be 1’-11” at the inlet and 2’-0 ½” at the outlet.
 - a. The existing conditions model predicts an inlet water depth of approximately 3-ft for Q1.1, which appears reasonable based on the measured water depths.
 - b. The relative difference in water depths between the inlet and outlet for Q1.1 in the existing conditions model is consistent with the measured difference of approximately 1 ½”.
2. As discussed previously, the bridge inspection report rating and description of waterway adequacy is “6 – Occasional Overtopping of Approaches – Insignificant Delays”. This appears generally consistent with the Flood Hazard map shown in Figure 4. The existing conditions model results appear generally consistent with both of these since it indicates that flows of Q50 and greater overtop the low point on the west roadway approach with the following approximate depths (see Figure 12):
 - a. 0.3 ft for Q50
 - b. 0.5 ft for Q100
 - c. 0.8 ft for Q500

- In West Cathance Stream downstream of the existing box culvert, widespread deposits of thin silt layers and flood-borne debris were observed on top of the streambanks and in some floodplain areas. Additionally, clumps of downed tree branches were deposited in multiple locations indicating flood-plain flows. These observations appear to indicate recent flood-plain inundation in some areas, likely during the previous autumn/winter.

Based on the available information, the model appears to be a reasonable approximation of the existing conditions.

Results from the existing conditions model indicate that the box culvert is submerged for Q2 and larger flows with roadway overtopping likely occurring for Q50 and larger flows. See Figure 12.

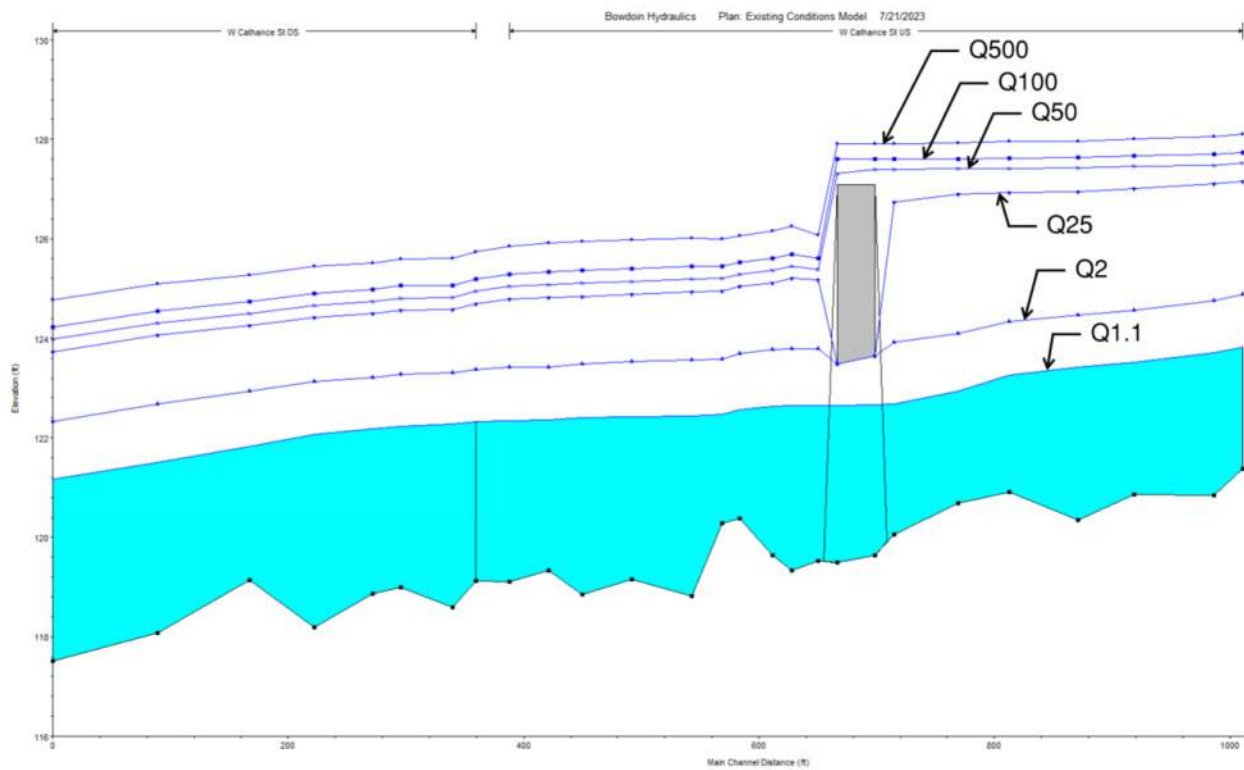


Figure 12 – Existing Conditions Model Water Surface Profiles for West Cathance Stream

Proposed Conditions Model

With a span of 22'-0", the proposed box culvert has a hydraulic opening of over 117 square feet, which is almost three times larger than the existing hydraulic opening of 40 square feet. It is expected to pass all flows up to and including the 500-year return period flow, thus reducing the expected frequency of roadway approach inundation. See Figure 13.

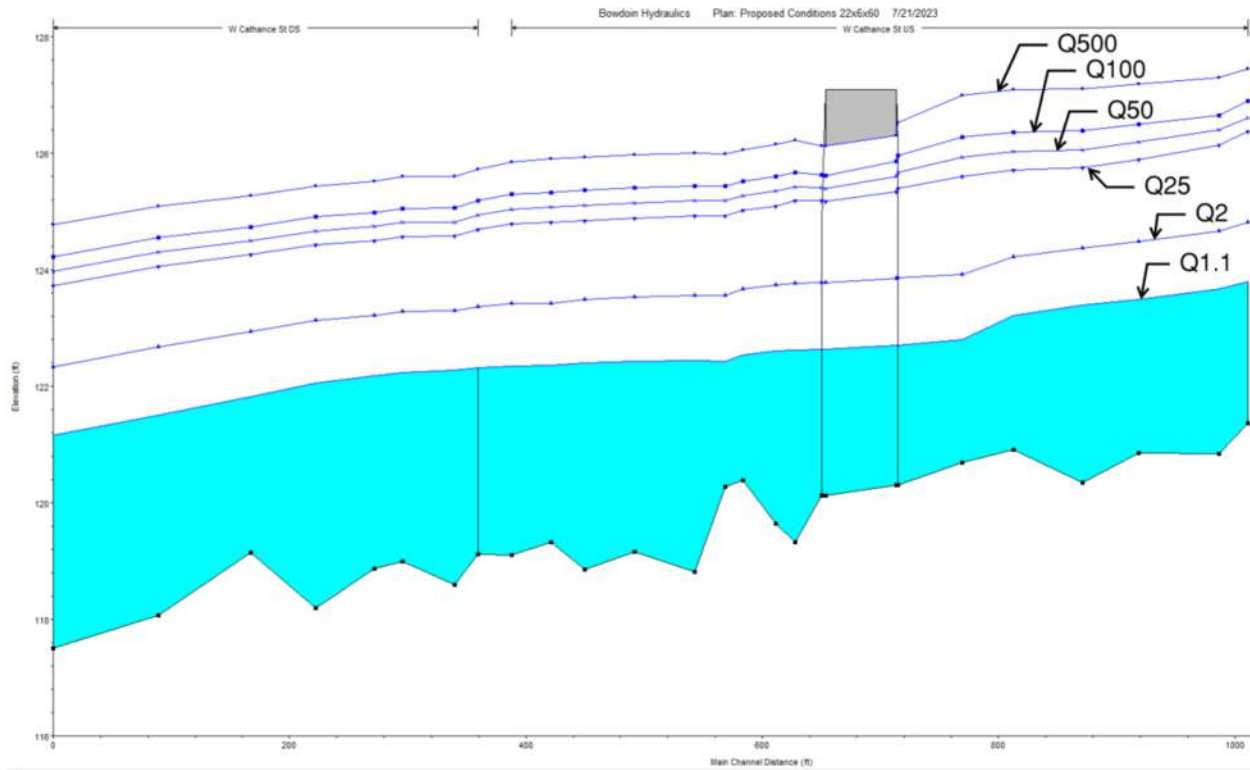


Figure 13 – Proposed Conditions Model Water Surface Profiles for West Cathance Stream

A comparison of the water surface profiles from the two models reveals:

1. For Q1.1 and Q2, the proposed conditions water surface elevations upstream of Lewis Bridge are very similar to the existing conditions.
2. For Q5 to Q500, the water surface elevations for the proposed conditions upstream of Lewis Bridge are improved compared to existing. See Table 2 for details.
3. No changes are expected in the water surface elevations downstream of the proposed culvert.

Table 2 - Summary of Hydraulic Analysis Results

Annual Exceedance Probability (AEP)	Return Period (years)	Upstream Water Surface Elevations (ft.)		
		Existing Conditions	Proposed Conditions	Change
90.9%	1.1	122.68	122.71	+0.03
50%	2	123.92	123.86	-0.06
4%	25	126.74	125.39	-1.35
2%	50	127.40	125.66	-1.74
1%	100	127.60	125.95	-1.65
0.2%	500	127.92	126.53	-1.39
		Discharge Velocity (ft./s)		
90.9%	1.1	1.40	1.35	-0.05
50%	2	1.98	1.74	-0.24
4%	25	3.80	3.17	-0.63
2%	50	4.33	3.59	-0.74
1%	100	4.86	4.01	-0.85
0.2%	500	6.12	4.99	-1.13
		Hydraulic Opening (sq. ft.)		
N/A	N/A	40	117	+77

* Upstream Water Surface Elevations at RS 30348.54 (BR US)
Downstream Discharge at RS 30283.71 (BR DS)

For additional hydraulic results, see Appendix D.

A comparison of the velocities in Table 2 yields:

1. For the existing conditions model, West Cathance Stream velocities away from Lewis Bridge are relatively low, even during the highest flows, because of the wide flood plain and roadway overtopping during higher flows. The model indicates the velocities to frequently be less than 3ft/sec in areas away from the existing culvert.
2. While stream velocities in the proposed culvert are lower than those in the existing culvert, for flows of approximately Q25 and higher the proposed velocities are still higher than in areas away from the culvert.

As can be seen in Table 3, the proposed box culvert meets the HW/D requirements for Q50 and Q100 with a theoretical low chord elevation at EL. 126.30 at the upstream limit of the culvert invert.

Table 3 – Headwater to Depth Ratios

<u>Annual Exceedance Probability (AEP)</u>	Return Period (years)	Headwater to Depth Ratios (HW/D)	HW/D Limit
2%	50	0.89	0.9
1%	100	0.94	1.0

The new culvert is expected to reduce flood impacts to the private properties upstream of Lewis Bridge on either side of the channel.

SCOUR ANALYSIS

A four-sided box culvert with a streambed constructed inside the box is proposed. Riprap aprons will be placed under the streambed materials at the culvert inlet and outlet. Additionally, a concrete toewall will be installed at both ends of the box culvert. Therefore, the box culvert is not susceptible to scour.