Note: Technical Appendices not included but can be provided upon request.

Memorandum

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VHB Project #: 55182.00
DOT W.I.N.: 22845.00

From: David Cloutier, P.E.
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Re: Habitat Connectivity Design Report
Hydraulic and Scour Report
Prestile Brook Crossing of ME Rt 164 (Main Street)
Caribou, Maine

VHB has prepared the following Level 2 hydraulic and scour analysis for the proposed replacement culvert carrying Maine Route 164 (Main Street) over Prestile Brook in Caribou, Maine. In addition to this analysis, VHB has evaluated the existing and proposed design for compatibility with Habitat Connectivity Design (HCD), consistent with the guidelines of the Maine Atlantic Salmon Programmatic Consultation (MAP) User Guide (March 2017). The location of the project is shown in Figure 1.

All elevations in this memorandum are referenced to the North American Vertical Datum of 1988 (NAVD88).

This memorandum has been revised to reflect the updated proposed culvert design as of January 8, 2020.

Existing Conditions

The existing crossing structure is a 140-foot long, 7.5-foot wide by 8-foot tall concrete box culvert with cast-in-place concrete wingwalls. The downstream end of the structure consists of a corrugated metal extension of the concrete box, comprising the final 20 feet of the structure. Plans are not available for the culvert; but are available for the 1999 reconstruction of Route 164. The culvert alignment is perpendicular to the roadway. Prestile Brook generally flows northeasterly through the crossing reach, curving to the left to briefly flow parallel to Route 164 for approximately 75 feet before making a sharp 90-degree bend to the right to enter the culvert. A 60-foot-long by 30-foot-wide scour pool is located at the outlet of the culvert. There is no evidence of scour protection at the culvert inlet or outlet, but there are some stone gabion walls in place to support the roadway embankment slopes.

Prestile Brook crosses Route 164 approximately 2 miles south of downtown Caribou, and approximately 4,000 feet upstream of the confluence of Prestile Brook with the Aroostook River. The brook flows through a narrow, deep valley approximately ½-mile wide and approximately 100 feet deep. Route 164 follows a vertical sag curve across this valley, but the roadway is still approximately 50 feet above the valley floor at the crossing location. The roadway runs along the top of a tall, steep embankment as wide as 160 feet at its base. The side slopes of this embankment are steeper than 2:1 and there is evidence of slumping and slope erosion.

The existing culvert presents a barrier to fish passage and to terrestrial wildlife passage. Flow depths through the culvert are too shallow and velocities are too high to support fish passage, and the length of the culvert impairs fish passage by restricting natural light. The downstream culvert outlet is not perched, but the large scour pool is inconsistent with natural stream composition through the crossing reach. The 50-tall roadway embankment presents a barrier to terrestrial wildlife passage, including deer and moose.

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Information Collection

For this evaluation, VHB reviewed the following data:

- Topographic field survey of the existing crossing, channel bathymetry, and surrounding area collected by MaineDOT in December 2017 and dated January 2018.
- Historic As-Built plans of the 1999 Route 164 roadway reconstruction (PIN 007407.00, Project No. STP-7407(00)X), provided by MaineDOT and dated February 2000.
- Proposed PDR/PIC plans for Prestile Hill Bridge, Route 164 (Bridge No. 6599 / Federal Project No. 2284500) prepared by VHB and dated January 7, 2020
- Current and historic USGS topographic maps and aerial imagery for Caribou, Maine.
- High-resolution (1-foot) LiDAR topographic data provided by MaineGIS and dated 2012.
- VHB conducted a field assessment of the crossing on June 19, 2018 to evaluate bridge hydraulics and stream geomorphology. Photographs are included in Appendix A.

The proposed crossing is located within flood Zone A as depicted on Flood Insurance Rate Map (FIRM) 230014, Panel 0014 C, Effective Date August 1, 1980. Zone A areas are determined by approximate methods; the Effective Flood Insurance Study (FIS) for the Town of Caribou (Community ID 230014), dated February 1, 1990, does not provide flood elevation data or other hydrologic/ hydrologic data for Prestile Brook. The crossing is not located within a regulatory floodplain, and therefore is not subject to the NFIP 60.3.(d)3 "No-Rise" requirement.

Stream Channel Characteristics

VHB conducted a field geomorphic assessment of the crossing location on June 19, 2018. Prestile Brook flows through a deep, heavily forested U-shaped valley in the crossing reach. The average channel bankfull width (BFW) is 17 feet and the valley floodplain varies in width from 120 to 200 feet, correlating to an entrenchment ratio of 7 to 11. The geomorphology of Prestile Brook changes significantly from upstream to downstream.

Upstream, an apparently man-made buried wooden weir structure approximately 400 feet upstream of the culvert serves as a grade control to maintain a gentle channel slope further upstream. This far upstream reach is characterized by sluggish flow and thick bank vegetation, with an abandoned breached beaver dam and beaver meadow approximately 700 feet upstream of the culvert. Below the weir, a large woody debris jam has blocked the main channel and the stream has jumped the right bank to scour away a new overflow channel. The channel downstream of the jam is laterally unstable and characterized by multiple scattered debris jams creating a braided channel pattern with extensive gravel and sand bars. The channel runs along the right (south) side of the valley, bending to the left when it encounters Route 164 to flow northerly along the toe of the embankment slope. There is evidence of significant bank erosion along the outer right bank of this channel bend, and a small potential bedrock outcrop is visible approximately 200 feet upstream of the culvert. The channel runs parallel to Route 164 for approximately 75 feet before bending sharply to the right to enter the culvert.

Downstream, the culvert outlets into a 60-foot-long by 30-foot-wide scour pool. An overflow channel continues straight at the far end of the pool, with the stream channel exiting over a cobble riffle at the far-left corner of the pool.

The downstream channel maintains consistent geomorphology for approximately 300 feet downstream of the scour pool, and VHB selected this section as the reference reach. The channel bends gently to the right, with BFW ranging from 14 to 18 feet and bank heights ranging from 1 to 3 feet. The channel shape is consistently trapezoidal through the reference reach, transitioning to a triangular shape with the thalweg along the outer bank at bends in the channel. Cobble riffles are spaced at approximately 50- to 75-foot intervals, and the channel is consistent with a pool-riffle classification. Channel bed material consists primarily of cobbles and gravel, and appears to be slightly armored from reduced sediment transport restricted by the culvert upstream. Average flow depths were approximately 0.5 feet at the time of the field assessment. Approximately 450 feet downstream of the culvert, the overflow channel re-enters the main channel on the right bank, creating a large gravel bar pushing flow to the left. A large woody debris jam is visible approximately 550 feet downstream of the culvert just beyond the limit of survey.

Throughout the study area, woody debris dominates the geomorphology of the channel. The floodplain is heavily forested and provides a consistent source of wood for debris jams and grade controls. Soils in the valley consist of glacial till with little to no boulders, and there is evidence that these soils are highly erodible by flood flows when the stream jumps the channel banks. The gravel-sand streambed appears highly mobile upstream with wood features driving channel profile elevations, while downstream the reduction in sediment transport has led to a more stable armored cobble bed.

Photographs of representative stream features are included in Appendix A.

Longitudinal Profile

MaineDOT collected survey of the Prestile Brook thalweg extending 450 feet downstream and 750 feet upstream of the existing culvert. This survey scope exceeds 20 times the average bankfull width, and extends sufficiently far upstream to identify the limit of influence of the culvert. An annotated profile of the Prestile Brook longitudinal profile is provided in Figure 2.

The longitudinal profile of Prestile Brook is consistent through the surveyed reach, with an overall channel slope of 1.2%. Downstream of Route 164, the channel (including the reference reach) has a consistent slope of 1.5%. Upstream of Route 164, the channel has a convex shape with a steeper reach at 1.6% within approximately 400 feet from the culvert, and a gentler slope of 0.7% further upstream. This grade break corresponds to the remnants of a buried wooden grade control structure set across the channel that appears to be man-made. Throughout the surveyed profile, cobble/gravel riffle crests and woody debris jams form grade controls.

VHB evaluated the lower Vertical Adjustment Profile (VAP) of the channel section based on the characteristics of the surveyed profile. The lower VAP was determined based on residual pool depths using USFS stream simulation methodology. Two pools were excluded from this determination: the scour pool at the existing culvert outlet, and the pool in the extremely narrow channel segment at the outlet of the abandoned beaver dam approximately 700 feet upstream of the culvert. Neither of these pools is representative of the channel geomorphology through the reference reach. Using the largest residual pool depth (1.6 feet), VHB developed the lower VAP line shown on Figure 2. Based on this analysis, and applying an adjustment factor of 2.0 to provide a factor of safety, the culvert streambed material (CSM) layer should be at least 3.2 feet thick to protect against long-term streambed degradation.

VHB also evaluated the higher VAP profile, based on topographic survey of the left (north) top of bank elevation concurrent with the thalweg profile. Channel banks range in height from 1.5 to 3.0 feet above the channel thalweg, representing maximum potential long-term streambed aggradation resulting from future log jams and/or new sediment influx.

The existing culvert inverts are depressed below the average longitudinal profile of the stream, and it appears that the existing structure has settled due to the weight of fill from the unusually tall roadway embankment. Culvert invert elevations from the 1999 As-Built roadway plans are nearly 1 foot higher than surveyed 2018 invert elevations, supporting this assumption.

Pebble Count

VHB and MaineDOT staff conducted a pebble count on June 19, 2018 within the reference reach of the channel, located approximately 100 to 250 feet downstream of the existing crossing. To reduce individual bias, the count was duplicated by multiple personnel and the results of the individual counts were combined into a composite total count. VHB also collected a grab sample of a deposit of finer material within the reference reach and performed a laboratory sieve analysis (Appendix B). Using the Flexible Combination method documented in Section 4.42 of the USFS General Technical Report RMRS-GTR-74, “Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring” (2001), VHB developed a composite gradation combining the results of the pebble counts and laboratory analysis to estimate representative streambed material gradation. Figure 3 presents the results of the pebble counts, laboratory analysis, and composite gradation.

The overall D50 of the pebble counts was approximately 50 mm (very coarse gravel), with a maximum observed pebble size of 330 mm (small boulder). Pebble counts collected at a riffle within the reference reach indicated a slightly larger D50 of 55 to 60 mm.

VHB did not perform a pebble count upstream of the existing culvert crossing. Visual assessment of stream channel material upstream indicates a smaller particle sizes (predominantly sand and gravel upstream compared to gravel and cobbles downstream). This difference can be attributed to differences in channel composition (established channel downstream versus braided unstable channel upstream) and to reduced hydraulic capacity through the culvert limiting the sediment supply to the downstream channel.

Proposed Preliminary Habitat Connectivity Design

Based on the results of the stream assessment, VHB recommends using a geomorphic-based stream simulation approach that mimics the natural stream conditions of the downstream reference reach. Although this reach does not represent a full stream simulation due to the reduced sediment supply, it will help provide a more stable base for an active channel bed transporting sediment from the upstream reach once the existing culvert restriction is removed. The proposed design will also need to incorporate a raised shelf along the top of the channel bank to provide passage for moose and other large wildlife in accordance with the FHWA "Wildlife Crossing Structure Handbook" (CFL/TD-11-003, March 2011).

The proposed design replaces the existing culvert with an open-bottom 30-foot span by 29-foot rise by 96-foot long precast concrete arch structure. The effective opening height of the structure is 21.7 feet, with abutment footings embedded to extend below predicted scour depths. Structure dimensions are designed to accommodate a moose passage shelf along the left (north) bank in addition to the stream channel. Moose passage design requirements result in a design that exceeds the 1.2 BFW requirement (1.2 x 17 feet = 21.4 feet).

FHWA guidance for moose passage calls for a pathway width greater than 10 feet and vertical clearance of at least 15 feet. The proposed design provides a 11-foot wide pathway with vertical clearance ranging from 6.7 feet at the abutment wall to 21.7 feet at the channel bank due to the culvert arch shape. Although the portion of the pathway closest to the abutment wall provides less than the recommended vertical clearance, over 75% of the pathway exceeds 15 feet of vertical clearance. Moose passage is also feasible within the stream channel under low flow conditions, as the entire width of the stream channel exceeds the vertical clearance requirement. The openness ratio of the proposed structure is 1.75 meters, over a tenfold improvement over the existing culvert. The moose passageway surface should consist of the same channel streambed material (CSM) as used in the stream channel, a cobble-gravel mixture based on the reference reach pebble count with sufficient fines to ensure minimum voids. Where riprap is placed for abutment or drainage swale protection, CSM should be placed over the riprap to ensure a smooth surface for moose passage. VHB also recommends installing a wildlife fence along the base of the roadway embankment slopes to guide animal movement towards the culvert crossing.

The proposed design adjusts the alignment of the culvert to a 15-degree skew instead of the perpendicular alignment of the existing culvert. This revised alignment will remove the sharp 90-degree bend at the existing culvert entrance and will result in a structure better aligned with the overall channel. Although this alignment results in a slightly larger disturbance of the existing stream than maintaining the existing alignment, it improves hydraulic performance and reduces potential scour by reducing sharp transitions in flow. The proposed roadway design will reduce embankment slopes to 2:1, resulting in a wider overall footprint; maintaining the existing alignment would have resulted in the embankment fill slope extending into the existing channel immediately upstream of the culvert. MaineDOT Highway and Environmental Staff discussed the implications of this design with VHB during an October 19, 2018 meeting and confirmed the skewed alignment.

Based on an evaluation of the longitudinal profile survey and the results of the geomorphic assessment, the proposed channel slope through the culvert will be set at a slope of 1.4% (Figure 2). This slope is consistent with the slope of the downstream reference reach and has been selected to provide a smooth transition between the channel upstream and downstream of the limit of work, accounting for the slight reduction in channel length due to the skewed culvert alignment.

The cross-sectional design of the streambed should be consistent with the measured dimensions of the reference reach, with a BFW of 17 feet and bank heights of 1.5 feet. VHB recommends including a 4-foot wide, 0.5-foot deep low-flow channel along the center of the streambed to ensure aquatic habitat connectivity until stream action establishes a natural channel morphology. Banklines should be set with the right bank along the face of the right culvert wall, with a 1- to 2-foot wide shelf along the top of the right bank for small animal passage. The left bank should be set 11 to 12 feet from the face of the left culvert wall to provide space for the moose passage shelf. Banklines should tie in to existing streambanks at the limit of work. Upstream of the culvert, VHB recommends gradually curving the banklines away from the channel to capture the entire width of the braided stream; this approach will ensure that the thalweg of the upstream channel will still flow to the culvert channel even as it fluctuates in location across the braided stream. Downstream of the culvert, VHB recommends continuing the right bankline through the existing scour pool to tie in to the existing bank where the downstream channel exits the pool. The existing large scour pool is inconsistent with the geomorphology of the natural stream channel, and maintaining a consistent BFW channel width through this section will eliminate a potential ecological barrier.

Table 1 provides a summary of the existing and proposed channel bankfull geometry:

Table 1 Bankfull Geometry

Watershed Area (mi^2)	Regression BFW (ft)	Measured BFW (ft)	Measured Channel Depth (ft)	1.2 BFW (ft)
5.2	21.5	17	1.5	21.4

Hydrologic Analysis

There is no stream gage data available for Prestile Brook. The MaineDOT Environmental Office prepared the hydrologic evaluation for this crossing using USGS Maine regression equations for ungaged streams. VHB applied the peak flow estimates from this hydrologic analysis for hydraulic modeling. Table 2 presents a summary of peak flows at the crossing; the hydrologic analysis is included in Appendix C.

Table 2 Hydrologic Data for Proposed Design

Drainage Area	5.2 sq. mi
Bankfull Discharge ($Q_{1.1}$)	97.9 cfs
Q_2	207.4 cfs
Q_5	331.7 cfs
Q_{10}	422.5 cfs
Q_{25}	554.6 cfs
Design Discharge (Q_{50})	654.7 cfs
Check Discharge (Q_{100})	767.0 cfs
Q_{500}	1,046.0 cfs
Flood of Record	Unknown

Hydraulic Analysis

VHB developed a hydraulic model using the US Army Corps of Engineers (USACE) HEC-RAS software, version 5.0.7, to evaluate hydraulic performance of existing conditions and of the proposed design. Hydraulic analysis included evaluation of the bankfull 1.1-year ($Q_{1.1}$), design discharge 50-year (Q_{50}), and check discharge 100-year (Q_{100}) flood events. VHB also evaluated the proposed design for low-flow conditions (represented by the May, August, and annual median flow rates) to evaluate fish passage conditions and to calibrate the model. Flow discharge rates were sourced from the hydrologic analysis provided by MaineDOT.

HEC-RAS model geometry is based on December 2017 topographic field survey of the culvert crossing and stream channel performed by MaineDOT, supplemented by 2012 MEGIS LiDAR topographic data of the extended floodplain, and proposed structure geometry. This revised memorandum incorporates changes to the proposed HEC-RAS model to reflect the October 1, 2019 Draft PIC design, most notably shortening the culvert length from 128 feet to 104 feet. VHB performed a sensitivity analysis of downstream boundary conditions, evaluating model results for critical depth and for normal depth using the longitudinal stream profile slope. Model results showed water surface profiles converging before the crossing, providing confidence in model results at the culvert. HEC-RAS model results are included in Appendix D. A summary of hydrologic and hydraulic data for the proposed design is presented in Table 3 below.

Table 3 Hydraulic Data Summary for Existing and Proposed Design

	Existing Culvert 7.5x8 ft box	Proposed Culvert 30 ft arch
Ordinary High Water ($Q_{1.1}$)	470.3 ft	470.1 ft
Discharge Velocity ($Q_{1.1}$)	11.8 fps	4.4 fps
Flow Topwidth in Culvert ($Q_{1.1}$)	7.5 ft	16.5 ft
Headwater Elevation (Q_{50})	476.3 ft	473.1 ft
Headwater Elevation (Q_{100})	478.0 ft	473.5 ft
Discharge Velocity (Q_{50})	18.8 fps	10.2 fps
Discharge Velocity (Q_{100})	21.0 fps	10.8 fps
Freeboard (Q_{50})	(submerged)	17.6 ft
Freeboard (Q_{100})	(submerged)	17.2 ft

Notes: 1.) Headwater elevation measured at HEC-RAS cross-section 461, 2 sections upstream of culvert
2.) Discharge velocity measured at HEC-RAS cross-section 300 BR D, downstream internal bridge section

HEC-RAS model results indicate freeboard well exceeding 2.0 feet for the Q_{50} design discharge and 1.0 ft for Q_{100}. The proposed design greatly increases the span and height the culvert, increasing the hydraulic opening of the structure. As a result, water levels and velocities for the proposed design are significantly lower than under existing conditions.

MaineDOT records indicate that Route 164 has overtopped during large flood events in the past. Based on the results of the HEC-RAS model, the existing culvert as adequately sized to convey discharges up to the Q_{500} event without overtopping the roadway. Given these model results and the extensive evidence of woody debris through the study reach, VHB assumes that past flooding was due to debris blocking the opening of the existing culvert. The proposed design should mitigate future flooding by providing a greater than 1.2x bankfull opening to pass floating woody debris, avoiding a blockage of the culvert.

Scour Analysis

VHB calculated bridge contraction and abutment maximum scour depths based on the methodology presented in Hydraulic Engineering Circular (HEC) 18 published by the FHWA in April 2012. Given the inherent variability in scour calculations, VHB evaluated scour for the proposed crossing both as a bridge (channel contraction scour plus local abutment scour) and as an open-bottom culvert. A summary of scour calculations is provided in Table 4 below; detailed scour calculations are included in Appendix E.

Table 4 Scour Analysis Results

	Q_{100} Design Scour Event	Q_{500} Check Scour Event
Discharge (cfs)	767	1,046
Average Channel Velocity (fps)	10.8	12.1
Contraction Scour (ft)[1]	0.0	0.1
Right Abutment Scour (ft)	4.0	4.7
Left Abutment Scour (ft)	4.3	5.5
Maximum Total Scour (at Left Abutment - ft)	4.3	5.6
Maximum Total Scour – Open-Bottom Culvert	3.2	5.6
Maximum Upstream Scour Elevation (ft NAVD88)[2]	464.7	463.4
Maximum Downstream Scour Elevation (ft NAVD88)[2]	463.3	462.0

Notes: 1.) Contraction scour analysis assumes clear-water scour based on pebble count D_{50}.
2.) Calculated from finish grade at abutment face.

The proposed culvert is aligned with the left (north) abutment set back 12 feet from the channel bank to provide space for moose passage; the right (south) abutment is set 1 foot behind the channel bank. Scour at the structure is a combination of contraction scour from the narrowing overbank flow area and abutment scour from overbank flows obstructed by the abutments. The proposed design contains bankfull flows within the established channel through the crossing, but the culvert structure and wingwalls are impacted by flow under larger flood events. Culvert foundations should be designed to maintain footing elevations below the calculated scour depths.