HYDROLOGY REPORT

Warren Brook originates from Passagassawakeag River in Belfast. Sheldon Bridge intersects Warren Brook about 3000 feet downstream of the brook's inlet. Warren Brook and Passagassawakeag River were both studied using approximate methods, which were reported by the Waldo County Flood Insurance Study (FIS, 2015).

According to the FIS, Waldo County has an average annual precipitation of 4.47 inches. The maximum average precipitation occurs in November. Northeasters are the most frequent type of storm in the area, and are most common in the winter months. Hurricanes are rare and occur in the late summer and early fall months. Flooding usually occurs in the winter and early spring due to heavy rainfall. Runoff from the heavy rainfall combined with the snowmelt in the spring will also cause flooding. Heavy rainfall with hurricanes and northeasters will occasionally cause flooding.

Hydrology was evaluated for Warren Brook by the Maine Department of Transportation Office-Hydrology Section. Peak flows were calculated with techniques described in the United States Geological Survey Water- Resources Investigations Report 99-4008 (Hodgkins, 1999) and in the United States Geological Survey- Scientific Investigations Report 2015-4059 (Lombard, 2015). The table below summarizes the flow events and the drainage area.

SUMMARY

Drainage Area	6.28	mi^2
Q1.1	88.8	ft^3/s
Q10	357.6	ft^3/s
Q25	469.7	ft^3/s
Q50	544.3	ft^3/s
Q100	637.8	ft^3/s
Q500	854.1	ft^3/s

Reported by: Nash, Kendra
Date: February 2, 2018

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

HYDRAULIC REPORT

The culvert runs through the Warren Brook below Poors Mill Road in Belfast. At the time of construction, the extreme high water was over the existing road. The road was raised about 4 feet at the bridge when it was built. Also the vertical opening of the bridge was increased about 16 inches. The ordinary high water was about 5 feet above the bottom of the streambed in the bridge. On October 27th, 2016 the water depth was about 1 foot in the arch and the stream was barely moving.

The hydraulics of the existing bridge and proposed alternatives were evaluated using HY-8 7.50 software. The complete HY-8 reports for the existing culvert and proposed alternatives are provided in Appendix E.

Below is a list of parameters used in the hydraulic model for the stream and for the existing culvert. The downstream is rocky and narrow and the stream bottom under the steel arch consists of dirt, sticks, leaves and some rocks. This information was used to select the manning's numbers for the hydraulic model.

Stream

- Cross section: Irregular; survey data was used to input stations and elevations of 32 points that represent the downstream.
- Manning's n:
    - Channel: 0.035
    - Overbanks: 0.070
- Downstream slope: 2.56%

Culvert

- Steel plate pipe arch on concrete footings: 21' span by 7'-11" rise
- Manning's n:
    - Top/ Sides: 0.024
    - Bottom: 0.035
- Inlet elevation: 133.6 feet
- Outlet elevation: 133.6 feet
- Culvert length: 65 feet
- Inlet configuration: mitered to conform to slope

The results of the analysis for the existing bridge are summarized at the end of this section. The clearance of the existing culvert is 2.3 feet at the Q50 event and 1.6 feet at the Q100 event. The headwater elevations to culvert depth (HW/D) ratios are 0.71 and 0.80 respectively. The BDG

recommends that the HW/D ratio be less than 0.9 during Q50 floods. Therefore, the existing culvert is adequate to meet hydraulic standards. At the Q1.1 flow, which is the yearly high flow, the estimated water depth is 20.4 inches and the estimated water velocity is 5.3 feet per second which are higher than the observed depth and velocity during a site visit in November. This is because the water was at low flow during the site visit.

The flood insurance rate map (FIRM) shows that during a Q100 flood, the stream floods into the floodplains, and over the road. Using the survey, it can be estimated that the Q100 elevation from the FIRM is approximately 143 to 144 feet. The Q100 headwater elevations are estimated to be approximately 140 feet from the HY-8 analysis. The peak discharges for the HY-8 analysis and for the FIS approximate method were both evaluated using USGS Regression Equations (Hodgkins, 1999). Drainage area for the approximate method is unknown. The drainage area for the HY-8 flows is 6.28 square miles. The watershed area for the approximate methods may be what is causing the Q100 flood elevation to be higher than the HY-8 Q100 flood elevation. The HY-8 analysis will be considered over the FIS approximate method, because the analysis parameters are known.

The parameters used for the replacement alternatives are below. The stream parameters are the same as the existing structure.

<u>Aluminum Box Culvert</u>

- 21’-10” span by 8’-5” rise with 24 inches of stream material fill
- Manning’s n:
    - Top/ Sides: 0.024
    - Bottom: 0.035
- Inlet elevation: 133.26’ (at top of special fill)
- Outlet elevation: 133.26’ (at top of special fill)
- Culvert length: 65’
- Inlet configuration: Square edge with headwall

<u>Precast Concrete Box Culvert</u>

- 21’ span by 9’ rise with 24 inches of stream material fill and 2’ wide by 1’ high banks on culvert sides
- Manning’s n:
    - Top/Sides: 0.012
    - Bottom: 0.035
- Inlet elevation: 130.00’ (at top of special fill)
- Outlet elevation: 129.53’ (at top of special fill)

- Culvert length: 95’
- Inlet configuration: Mitered to conform to slope

The results of the analyses for the proposed alternatives are summarized at the end of this section. The aluminum box culvert is estimated to have a clearance of 3.6’ and 3.0’ during the Q50 and Q100 events respectively. The HW/D ratios are 0.80 and 0.88 respectively. The estimated clearance of the concrete box culvert is estimated to be 1.5’ and 0.9’ during the Q50 and Q100 events respectively. The HW/D ratios are 0.79 and 0.87 respectively. Both proposed alternatives meet BDG hydraulic recommendations. The clearances for the Q50 and Q100 events for the alternative options are about a half foot less than the existing alternative. The rises of the alternative options are actually higher than the existing rise, but the stream material will take up two feet, reducing the opening and decreasing the clearance.

SUMMARY

		Existing Structure	Recommended Structure	
		21' x 7'11" Steel Arch	21' x 9' Precast Concrete Box Culvert with 2' of Special Fill	21'-2" x 8'-10" Aluminum Box Culvert with 2' of Special Fill
Total Area of Waterway Opening*	ft^2	107	147	115.6
Headwater elevation @ $Q_{1.1}$	ft	135.0	132.0	131.5
Headwater elevation @ Q_{10}	ft	137.5	134.3	133.5
Headwater elevation @ Q_{25}	ft	138.3	135.0	134.2
Headwater elevation @ Q_{50}	ft	138.9	135.5	134.7
Headwater elevation @ Q_{100}	ft	139.6	136.1	135.2
Headwater elevation @ Q_{500}	ft	141.1	137.3	136.3
Clearance @ Q_{50}	ft	2.3	1.5	1.4
Clearance @ Q_{100}	ft	1.6	0.9	0.8
HW/D @ Q_{50}		0.71	0.79	0.80
HW/D @ Q_{100}		0.80	0.87	0.88
*Waterway opening for proposed structures does not include special fill area				
Outlet Velocity @ $Q_{1.1}$	ft/s	5.3	4.0	3.1
Outlet Velocity @ Q_{10}	ft/s	8.4	8.2	7.3
Outlet Velocity @ Q_{25}	ft/s	9.6	9.0	8.5
Outlet Velocity @ Q_{50}	ft/s	10.1	9.4	9.2
Outlet Velocity @ Q_{100}	ft/s	10.8	9.9	9.9
Outlet Velocity @ Q_{500}	ft/s	12.2	11.0	10.9

Reported by: Nash, Kendra
Date: February 6, 2018

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

HY-8 Culvert Analysis Report

Crossing Discharge Data

Discharge Selection Method: User Defined

Site Data - Proposed Aluminnum Box Culvert

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 127.92 ft

Outlet Station: 65.00 ft

Outlet Elevation: 127.60 ft

Number of Barrels: 1

Culvert Data Summary - Proposed Aluminnum Box Culvert

Barrel Shape: User Defined

Barrel Span: 21.17 ft

Barrel Rise: 8.83 ft

Barrel Material: Corrugated Metal Riveted or Welded

Embedment: 24.00 in

Barrel Manning's n: 0.0350 (top and sides)

Manning's n: 0.0350 (bottom)

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: None

Roadway Data for Crossing: Proposed- Aluminum

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 100.00 ft

Crest Elevation: 144.00 ft

Roadway Surface: Paved

Roadway Top Width: 22.70 ft

Tailwater Channel Data - Proposed- Aluminum

Tailwater Channel Option: Irregular Channel

Channel Slope: 0.0256

User Defined Channel Cross-Section:

Coord No.	Station (ft)	Elevation (ft)	Manning's n
1	0.00	150.00	0.0700
2	5.30	149.00	0.0700
3	13.63	148.00	0.0700
4	22.63	147.00	0.0700
5	31.60	146.00	0.0700
6	40.58	145.00	0.0700
7	49.56	144.00	0.0700
8	60.91	143.00	0.0700
9	75.60	142.00	0.0700
10	84.10	141.00	0.0700
11	92.19	140.00	0.0700
12	113.91	139.00	0.0700
13	132.12	138.00	0.0700
14	146.12	137.00	0.0700
15	155.41	136.00	0.0700
16	159.79	135.00	0.0700
17	163.84	134.00	0.0700
18	169.07	133.00	0.0700
19	175.62	132.00	0.0700
20	182.74	131.00	0.0700
21	183.14	130.85	0.0350
22	190.26	130.00	0.0350
23	201.85	130.00	0.0350
24	204.14	131.00	0.0700
25	205.42	132.00	0.0700
26	223.81	133.00	0.0700
27	237.17	134.00	0.0700
28	250.53	135.00	0.0700
29	264.48	135.00	0.0700
30	279.42	134.00	0.0700
31	292.86	133.00	0.0700
32	310.04	133.00	0.0000

Table 1 - Summary of Culvert Flows at Crossing: Proposed- Aluminum

Headwater Elevation (ft)	Discharge Names	Total Discharge (cfs)	Proposed Aluminnum Box Culvert Discharge (cfs)	Roadway Discharge (cfs)	Iterations
131.45	Q1.1	88.80	88.80	0.00	1
133.52	Q10	357.60	357.60	0.00	1
134.22	Q25	469.70	469.70	0.00	1
134.65	Q50	544.30	544.30	0.00	1
135.17	Q100	637.80	637.80	0.00	1
136.28	Q500	854.10	854.10	0.00	1
144.00	Overtopping	2287.50	2287.50	0.00	Overtopping

Table 2 - Culvert Summary Table: Proposed Aluminnum Box Culvert

Discharge Names	Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
Q1.1	88.80	88.80	131.45	1.179	1.525	3-M1t	1.188	0.810	1.356	0.954	3.094	5.600
Q10	357.60	357.60	133.52	2.987	3.599	3-M2t	2.743	2.076	2.322	1.920	7.276	8.921
Q25	469.70	469.70	134.22	3.573	4.294	3-M2t	3.231	2.490	2.613	2.211	8.492	9.529
Q50	544.30	544.30	134.65	3.937	4.729	3-M2t	3.530	2.745	2.786	2.384	9.230	9.767
Q100	637.80	637.80	135.17	4.393	5.247	2-M2c	3.882	3.053	3.053	2.583	9.869	9.960
Q500	854.10	854.10	136.28	5.378	6.362	2-M2c	4.626	3.693	3.693	2.983	10.927	10.196

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Straight Culvert

Inlet Elevation (invert): 129.92 ft, Outlet Elevation (invert): 129.60 ft

Culvert Length: 65.00 ft, Culvert Slope: 0.0050

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Table 3 - Downstream Channel Rating Curve (Crossing: Proposed- Aluminum)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
88.80	130.95	0.95	5.60	1.52	1.14
357.60	131.92	1.92	8.92	3.07	1.34
469.70	132.21	2.21	9.53	3.53	1.42
544.30	132.38	2.38	9.77	3.81	1.45
637.80	132.58	2.58	9.96	4.13	1.46
854.10	132.98	2.98	10.20	4.76	1.45

HY-8 Culvert Analysis Report

Crossing Discharge Data

Discharge Selection Method: User Defined

Site Data - Precast Concrete Box Culvert

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 130.00 ft

Outlet Station: 95.00 ft

Outlet Elevation: 129.53 ft

Number of Barrels: 1

Culvert Data Summary - Precast Concrete Box Culvert

Barrel Shape: User Defined

Barrel Span: 21.00 ft

Barrel Rise: 7.00 ft

Barrel Material: Concrete

Embedment: 0.00 in

Barrel Manning's n: 0.0120 (top and sides)

Manning's n: 0.0360 (bottom)

Culvert Type: Straight

Inlet Configuration: Thin Edge Projecting

Inlet Depression: None

Roadway Data for Crossing: Proposed- Concrete with banks

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 100.00 ft

Crest Elevation: 144.00 ft

Roadway Surface: Paved

Roadway Top Width: 22.70 ft

Tailwater Channel Data - Proposed- Concrete with banks

Tailwater Channel Option: Irregular Channel

Channel Slope: 0.0256

User Defined Channel Cross-Section:

Coord No.	Station (ft)	Elevation (ft)	Manning's n
1	0.00	150.00	0.0700
2	5.30	149.00	0.0700
3	13.63	148.00	0.0700
4	22.63	147.00	0.0700
5	31.60	146.00	0.0700
6	40.58	145.00	0.0700
7	49.56	144.00	0.0700
8	60.91	143.00	0.0700
9	75.60	142.00	0.0700
10	84.10	141.00	0.0700
11	92.19	140.00	0.0700
12	113.91	139.00	0.0700
13	132.12	138.00	0.0700
14	146.12	137.00	0.0700
15	155.41	136.00	0.0700
16	159.79	135.00	0.0700
17	163.84	134.00	0.0700
18	169.07	133.00	0.0700
19	175.62	132.00	0.0700
20	182.74	131.00	0.0700
21	183.14	130.85	0.0350
22	190.26	130.00	0.0350
23	201.85	130.00	0.0350
24	204.14	131.00	0.0700
25	205.42	132.00	0.0700
26	223.81	133.00	0.0700
27	237.17	134.00	0.0700
28	250.53	135.00	0.0700
29	264.48	135.00	0.0700
30	279.42	134.00	0.0700
31	292.86	133.00	0.0700
32	310.04	133.00	0.0000

Table 1 - Summary of Culvert Flows at Crossing: Proposed- Concrete with banks

Headwater Elevation (ft)	Discharge Names	Total Discharge (cfs)	Precast Concrete Box Culvert Discharge (cfs)	Roadway Discharge (cfs)	Iterations
131.95	Q1.1	88.80	88.80	0.00	1
134.27	Q10	357.60	357.60	0.00	1
135.03	Q25	469.70	469.70	0.00	1
135.51	Q50	544.30	544.30	0.00	1
136.07	Q100	637.80	637.80	0.00	1
137.29	Q500	854.10	854.10	0.00	1
144.00	Overtopping	1947.44	1947.44	0.00	Overtopping

Table 2 - Culvert Summary Table: Precast Concrete Box Culvert

Discharge Names	Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
Q1.1	88.80	88.80	131.95	1.533	1.954	3-M2t	1.597	1.200	1.428	0.953	4.037	5.603
Q10	357.60	357.60	134.27	3.310	4.269	2-M2c	3.235	2.464	2.464	1.919	8.173	8.928
Q25	469.70	469.70	135.03	3.983	5.031	2-M2c	3.756	2.879	2.879	2.210	8.952	9.537
Q50	544.30	544.30	135.51	4.451	5.506	2-M2c	4.078	3.141	3.141	2.383	9.391	9.775
Q100	637.80	637.80	136.07	5.039	6.073	2-M2c	4.459	3.445	3.445	2.581	9.913	9.969
Q500	854.10	854.10	137.29	6.330	7.290	7-M2c	5.269	4.092	4.092	2.981	10.958	10.205

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Straight Culvert

Inlet Elevation (invert): 130.00 ft, Outlet Elevation (invert): 129.53 ft

Culvert Length: 95.00 ft, Culvert Slope: 0.0050

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Table 3 - Downstream Channel Rating Curve (Crossing: Proposed- Concrete with banks)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
88.80	130.95	0.95	5.60	1.53	1.14
357.60	131.92	1.92	8.93	3.07	1.34
469.70	132.21	2.21	9.54	3.54	1.42
544.30	132.38	2.38	9.77	3.81	1.45
637.80	132.58	2.58	9.97	4.13	1.46
854.10	132.98	2.98	10.21	4.77	1.45