Hydraulic Report

Bruce Freeman Rail Trail
over Pantry Brook
Sudbury, Massachusetts

April 24, 2020

PREPARED FOR:

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1.0 Executive Summary

This project involves the replacement of an existing 12 foot single span structure on the Bruce Freeman Rail Trail over Pantry Brook in Sudbury, Massachusetts. The existing bridge spans over an area delineated by the National Flood Insurance Program (NFIP) as Zone AE, which is a 100-year flood boundary where base flood elevations and hazard factors have been determined.

The proposed bridge replacement is a single span arch structure with a 34-foot clear span. Dumped riprap will be placed between the new footing and old abutments for scour protection and will reduce the hydraulic opening to a maximum width of approximately 25'-6", which accommodates environmental criteria.

The contributing watershed area is measured to be approximately 2.5 square miles. The hydraulic design flood for a rail trail is the 10-year event. The estimated peak discharge for the 10-year flood is 155 cfs. Furthermore, the proposed bridge structure does not increase the base flood elevation.

A scour design return frequency for this project consists of the 25-year event, and the scour check return frequency is the 50-year event. The scour safety analysis for the proposed structure estimates a total scour depth of 0.6 feet and 0.7 feet, respectively.

Scour countermeasures shall include dumped riprap for the proposed slopes from the main channel to the proposed abutments.

2.0 Project Description

2.1 Existing Structure

The existing bridge structure is located in the Town of Sudbury, Massachusetts. The structure number for this bridge is S31013-BF2-DOT-RRO. The existing bridge is a 12 foot single span structure consisting of steel beams with an open timber tie deck and stone abutments. The curb to curb width is 14'-0".

A portion of the north abutment supporting the superstructure has failed and stones have fallen into the waterway resulting in the steel beam supports of the superstructure to settle.

2.1.1 Crossed Waterway

The waterway crossed by this bridge is Pantry Brook. This watershed at the project location consists of two main tributaries that consist of Pantry Brook and Mineway Brook. The confluence of these two streams is located directly upstream of the bridge at the project location.

The headwaters to Pantry Brook originate from some unnamed ponds and flow in the southerly direction through the Town of Sudbury to the project location. The headwaters to Mineway Brook originate at Goodman Hill and flow in the northerly direction through the Town of Sudbury to the project location. Pantry Brook flows in the easterly direction from the project location to its confluence with the Sudbury River. The drainage area at the crossing site is approximately 2.5 square miles.

The history of any ice floes at this bridge is unknown.

2.1.2 Highway Conveyed

The roadway conveyed by the existing bridge structure is an abandoned rail road. This railroad layout consists of a single track layout and the existing width of the timber bridge deck is approximately 16'-6".

2.1.3 Land Uses in Vicinity of Bridge

Land use in the vicinity of the bridge primarily consists agricultural land, grassed fields, and wetlands with forested land separating these areas.

The closest residential development is located to the north and southwest approximately 700 feet from the bridge location. A residential development with approximately 1-acre lots sizes is located south and west of the project location.

2.1.4 Special Site Considerations

The National Flood Insurance Program (NFIP) indicates that the existing bridge is within the 100-Year flood zone for Pantry Book.

2.2 Proposed Action

The proposed bridge replacement is a single span arch structure with a 34-foot clear span and 16'-6" deck width (out-to-out). Each proposed footing will be constructed approximately 11 feet behind the face of existing abutments. Dumped riprap will be placed between the new footing and old abutments for scour protection and will reduce the hydraulic opening to a maximum width of approximately 25'-6", which accommodates environmental criteria. The proposed structure will have a minimum cover of approximately 2.5 feet.

3.0 <u>Data Collection</u>

3.1 Data Sources

References and data sources utilized for the hydraulic analysis and design of this project include:

- MassDOT Load and Resistance Factor Design (LRFD) Bridge Manual, January 2020 Revision (as provided by MassDOT)
- Maynard, USGS Topographic Map, Scale 1:24,000.
- National Flood Insurance Program (NFIP), Flood Insurance Rate Map (FIRM), Town of Sudbury, MA, Panel 366 of 656 (Map Number: 25017C0366F), July 7, 2014.
- National Flood Insurance Program (NFIP), Flood Insurance Rate Map (FIRM), Town of Sudbury, MA, Panel 368 of 656 (Map Number: 25017C0368F), July 7, 2014.
- Flood Insurance Study (FIS), Middlesex County, MA, Volume 1 (FIS Number: 25017CV001C), Revised: July 6, 2016.
- Flood Insurance Study (FIS), Middlesex County, MA, Volume 2 (FIS Number: 25017CV002C), Revised: July 6, 2016.
- Flood Insurance Study (FIS), Middlesex County, MA, Volume 6 (FIS Number: 25017CV006C), Revised: July 6, 2016.
- Geotechnical Particle Size Distribution Report, Boring BB-101, Sample S9, Thielsch Engineering, Inc., September 16, 2019.
- Geotechnical Particle Size Distribution Report, Boring BB-102A, Sample S9, Thielsch Engineering, Inc., September 16, 2019.

- Federal Highway Administration (FHWA), Hydraulic Engineering Circular Number 18, *HEC-18 Evaluating Scour at Bridges*, April 2012.
- Federal Highway Administration (FHWA), Hydraulic Engineering Circular Number 23, *HEC-23 Bridge Scour and Stream Instability Countermeasures*, March 2001.

Uses of these references are discussed in further detail in the methodology portions of this report. All elevations referenced in the report are in feet, vertical datum NAVD 88.

4.0 Engineering Methods

4.1 Hydrologic Analysis

The watershed area for the project location is found within the FEMA National Flood Insurance Program (NFIP) and consists of two tributaries, Pantry Brook and Mineway Brook. Based on the information received from FEMA, these two waterways were studied at different times. The Pantry Brook watershed was studied in 1977 and Mineway Brook watershed was studied in 1998. The base flood elevations published in the Flood Insurance Study (FIS) for Pantry Brook are based on the Pantry Brook Study. The FEMA hydraulic model for Pantry Brook can be found in Appendix 6.1.

Flow data for the 100-year and 500-year return frequency on this project was obtained from the Pantry Brook hydraulic model completed in 1977. This was necessary to complete the "No-Rise" hydraulic analysis for the project since the base flood elevations were determined from this study. A complete summary of discharges from the Pantry Brook Study are below:

Table 4-1: Summary of FEMA Discharge Flow Rates

		Return Frequency			
River Name	**Drainage Area (mi^2)**	**10-year (cfs)**	**50-year (cfs)**	**100-year (cfs)**	**500-year (cfs)**
Pantry Brook	2.5	155	206	240	326

The USGS StreamStats regression analysis, found in Appendix 6.2, was utilized to obtain flow data for design flows consisting of the 10, 25, and 50-year return frequency. A summary of the estimated peak discharges for design are below:

Table 4-2: Summary of Design Discharge Flow Rates

		Return Frequency			
River Name	**Drainage Area (mi^2)**	**2-year (cfs)**	**10-year (cfs)**	**25-year (cfs)**	**50-year (cfs)**
Pantry Brook	2.5	71	155	209	253

4.2 Hydraulic Analysis

The hydraulic design flood return frequency for this project is a 10-year event. This project is also located within an NFIP floodplain designated Zone AE. Therefore, it is necessary to obtain the effective hydraulic model from FEMA and perform a "No-Rise" analysis for this project.

The U.S. Army Corps of Engineers (USACOE), Hydrologic Engineering Center River Analysis System (HEC-RAS) program, Version 5.0.7, will be utilized for the hydraulic analysis. The FEMA HEC-2 model was converted to a steady flow HEC-RAS model that extends from FEMA Section A to Section D as shown on the FIRMETTE. This is equivalent to approximately 2,400 feet downstream and 2,300 feet upstream of the project location. Additional sections were added to the HEC-RAS model upstream and downstream of the bridge location using survey completed for the project in the spring of 2019.

Manning's "n" values for the channel and overbank areas were obtained from the FEMA HEC-2 model and are 0.035 and .005, respectively. The contraction and expansion coefficients were held constant at 0.1 and 0.3 values, respectively at open stream cross sections and increased to 0.3 and 0.5, respectively at sections near the bridge location. Critical depth was used for the downstream boundary condition as done in the effective hydraulic model from FEMA.

The FIRM maps and FIS floodway data and flood profile are included in Appendix 6.3.

4.2.1 No-Rise Hydraulic Analysis

This project is located within an NFIP floodplain designated Zone AE, which requires a "No-Rise" analysis to be performed in accordance with Section 1.3.5 of the MassDOT Bridge Manual. To begin the analysis, a copy of the waterway's effective NFIP hydraulic model was obtained from FEMA.

The information received from FEMA included the two waterways, Pantry Brook and Mineway Brook, that combine upstream of the project location, and the data shows that these waterways were studied at different times. The Pantry Brook watershed was studied in 1977 and Mineway Brook watershed was studied in 1998.

The FEMA model provided for Pantry Brook consisted of a HEC-2 model in PDF format. Elevations from the HEC-2 model were converted from NGVD 29 to NAVD 88 and then compared to the FIS base flood elevations. This revealed that the HEC-2 model and FIS contained the same base flood elevation data, which verifies that the HEC-2 model should be used for the "no-rise" analysis.

4.2.2 Duplicate Effective Model

A steady flow analysis recreating the effective FEMA HEC-2 model was developed using HEC-RAS by manually converting the HEC-2 data and inputting the information into a HEC-RAS model. The model extends from FEMA Section A to Section D as shown on the FIRMETTE. The duplicate effective model reproduces the effective base flood elevation profile within the required 0.5 feet. A summary of results for the duplicate effective model is provided in the following table:

Table 4-3: Summary of Duplicate Effective Model Results

River Station	FIS Cross-Section	[1] Published Data (Feet, NAVD 88)	[2] Duplicated/Corrected Effective Model (Feet, NAVD 88)	[2] - [1]
1.4	A	114.72	114.73	0.01
1.5		115.02	115.05	0.03
1.6		115.11	115.13	0.02
1.7		115.16	115.19	0.03
7.3		117.11	117.10	-0.01
12.4		118.92	118.95	0.03
14.0		120.48	120.45	-0.03
14.7		120.62	120.64	0.02
15.0	Bridge			
15.25		120.75	121.23	0.48
15.8		121.05	121.30	0.25
15.81		120.88	121.19	0.31
16.0	Bridge			
16.03		122.20	122.68	0.48
16.04		123.15	122.68	-0.47
17.0		123.44	123.09	-0.35
19.8	B	123.45	123.11	-0.34
25.4		123.48	123.12	-0.36
26.15		123.33	122.98	-0.35
26.2	Bridge (Project Location)			
26.25		123.35	123.01	-0.34
27.1		123.74	123.54	-0.20
30.3	C	123.78	123.56	-0.22
34.8		124.16	123.98	-0.18
39.3	D	124.66	124.65	-0.01
44.9		127.50	127.38	-0.12
49.4	E	131.11	131.43	0.32

4.2.3 Existing Conditions Model

An existing conditions model was created from the duplicate effective model by incorporating additional river sections upstream and downstream of the bridge location using survey completed for the project. No other changes were made to the model. Results for the existing conditions hydraulic model are included in Appendix 6.4.

4.2.4 Proposed Condition Model

The proposed conditions model was created by replacing the existing bridge with the proposed structure. Two river sections located at the upstream and downstream face of the existing bridge were removed so the proposed structure could be added to the model. The two river sections removed from the proposed condition model were sections 26.15 and 26.25. The hydraulic performance of the existing and proposed structures are compared at river section 26.4. Results for the proposed conditions hydraulic model are included in Appendix 6.5. A summary of hydraulic performance and base flood elevation model comparison can be found in the following tables:

Table 4-4: Summary of Hydraulic Performance

		Existing		Proposed	
Return Frequency	**Peak Flow (CFS)**	**SWEL (FT)**	**Velocity (FT/s)**	**SWEL (FT)**	**Velocity (FT/s)**
10-Year	155	121.91	2.64	121.66	2.89
25-Year	209	122.45	2.99	122.06	3.38
50-Year	253	123.50	2.72	123.23	2.91
100-Year	240	123.40	2.64	123.16	2.82
500-Year	326	124.20	2.83	123.84	3.20

Table 4-5: Comparison of Hydraulic Performance for the Base Flood Elevation (BFE)

Model Cross Sections	FIS Cross-Section	[1] Duplicated/ Corrected Effective Model BFE (Feet, NAVD 88)	[2] Existing Condition Model (Feet, NAVD 88)	[3] Proposed Condition Model (Feet, NAVD 88)	[3] - [2] Project Impact	[3] - [1] No-Rise Evaluation
1.4	A	114.7	114.7	114.74	0.00	0.01
1.5		115.1	115.1	115.06	0.00	0.01
1.6		115.1	115.1	115.14	0.00	0.01
1.7		115.2	115.2	115.20	0.00	0.01
7.3		117.1	117.1	117.11	0.00	0.01
12.4		119.0	119.0	118.96	0.00	0.01
14		120.5	120.5	120.46	0.00	0.01
14.7		120.6	120.6	120.64	0.00	0.00
15.0	Bridge					
15.25		121.2	121.2	121.24	0.00	0.01
15.8		121.3	121.3	121.31	0.00	0.01
15.81		121.2	121.2	121.20	0.00	0.01
16.0	Bridge					
16.03		122.7	122.7	122.69	0.00	0.01
16.04		122.7	122.7	122.69	0.00	0.01
17.0		123.1	123.1	123.10	0.00	0.01
19.8	B	123.1	123.1	123.12	0.00	0.01
21.2		Note 1	123.1	123.12	0.00	n/a
22.3		Note 1	123.1	123.13	0.00	n/a
23.2		Note 1	123.1	123.13	0.00	n/a

Model Cross Sections	FIS Cross-Section	[1] Duplicated/ Corrected Effective Model BFE (Feet, NAVD 88)	[2] Existing Condition Model (Feet, NAVD 88)	[3] Proposed Condition Model (Feet, NAVD 88)	[3] - [2] Project Impact	[3] - [1] No-Rise Evaluation
24.3		Note 1	123.1	123.13	0.00	n/a
25.4		123.1	123.1	123.12	0.00	0.00
25.65		Note 1	123.2	123.16	0.00	n/a
25.9		Note 1	123.1	123.12	0.04	n/a
26.15		123.0	123.0	Note 2	n/a	n/a
26.2	Bridge					
26.25		123.0	123.0	Note 2	n/a	n/a
26.4		Note 1	123.4	123.16	-0.24	n/a
26.5		Note 1	123.6	123.31	-0.24	n/a
27.1		123.5	123.6	123.33	-0.23	-0.21
30.3	B	123.6	123.6	123.34	-0.23	-0.22
34.8		124.0	124.0	123.94	-0.05	-0.04
39.3	D	124.7	124.7	124.65	-0.01	0.00
44.9		127.4	127.4	127.39	0.00	0.01
49.4	E	131.4	131.4	131.44	0.00	0.01

Note 1: River section added in existing condition model. Water surface elevation not available.
Note 2: River section removed from model to accommodate proposed bridge structure.

4.3 Scour / Stability Analysis

A scour safety assessment was performed in accordance with Section 1.3.3.5 of the MassDOT Bridge Manual. The NCHRP 24-20 Abutment Scour Approach in HEC-18 was used to calculate the total abutment scour depth. These scour calculations are included in Appendix 6.6

Two soil borings were taken in the vicinity of the bridge. The samples predominantly contained silty sands or sand with silt at a depth of 16-18 feet below the abandoned railroad surface. A particle grain size analysis was performed for both samples to determine the streambed D_{50} particle size and the results are included in Appendix 6.6.

The NCHRP 24-20 abutment scour method utilizes the ratio between the projected length of embankment divided by the width of the floodplain to determine the scour condition for the structure. The two scour conditions consist of clear-water scour and live-bed scour. The existing and proposed structures for this project experience live-bed scour, which does not use the D_{50} particle size in the equation.

Scour was evaluated for the design flood return frequencies in accordance with Table 1.3.4-1 of the MassDOT Bridge Manual. The Scour Design Flood Return Frequency is 25 years, and the Scour Check Flood Return Frequency is 50 years. Both the Scour Design and Scour Check Flood Return Frequencies were used to estimate total abutment scour. The NCHRP scour calculations are included in Appendix 6.6, and a summary of calculated abutment scour depths are found in the following table:

Table 4-6: Summary of Calculated Scour for Bridge

Alternative	Return Frequency (Year)	Design Abutment Scour Depth (Feet)
Existing Condition	25	5.0
	50	6.3
Proposed Condition	25	0.6
	50	0.7

4.4 Scour Countermeasure Design

To protect against potential scour problems at the proposed bridge, riprap protection is a necessary countermeasure along the abutments. The stream velocity and flow depth were obtained from the HEC-RAS model for the 50-year hydraulic design flood return frequency. This information was used to determine the size and thickness of riprap scour countermeasures as evaluated in HEC-23. The estimated D_{50} stone size is 1.8 inches, with a minimum layer thickness of 2.7. The riprap calculation is included in Appendix 6.7. Dumped Riprap (MassDOT Standard Specification M2.02.2) will meet the D_{50} stone size for this project.

Table 4-7: Summary of Scour Countermeasure Design at Bridge Abutments

Alternative	Riprap Size D_{50} (Inches)	Riprap Thickness (Inches)
Existing Condition	6.57	9.86
Proposed Condition	1.77	3.54