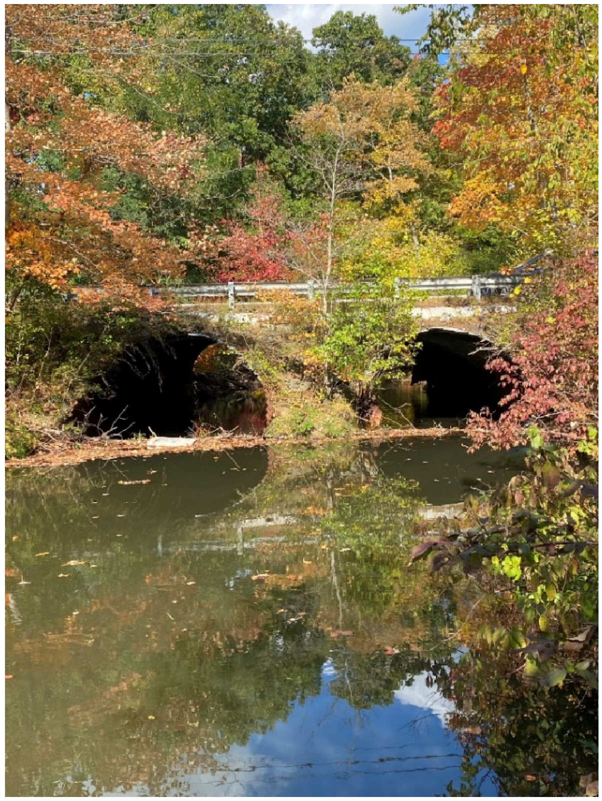
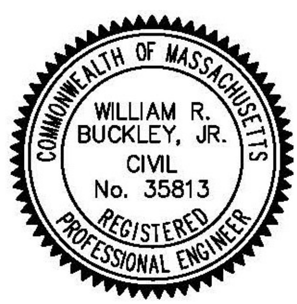
HYDRAULIC STUDY REPORT

Chestnut Street over Ipswich River
North Reading, Middlesex County, Massachusetts
Bridge No. N18003-2D4-MUN-NBI
PROJECT No. 22-0171



November 18, 2022
revised June 13, 2024
revised September 24, 2024
revised October 11, 2024

Prepared by:
Bay Colony Group, Inc.
4 School Street
Foxborough, MA 02035
508.543.3939



Prepared for:
TEC - The Engineering Corp
282 Merrimack Street, 2d Floor
Lawrence, MA 01843
978.794.1792

Table of Contents

List of Tables

List of Figures

1.0 Executive Summary

The purpose of this technical report is to present the results of a study conducted at the culvert conveying the Ipswich River under Chestnut Street in North Reading, MA in order to evaluate the hydraulic performance of the existing culvert and to develop an alternative design. This report was prepared in a manner consistent with the Massachusetts Department of Transportation (MassDOT) guidelines for preparation of hydraulic studies at bridge sites modified to account for the preliminary nature of the design.

The scope of this investigation consisted of a review of pertinent hydrologic analysis data for the Ipswich River at the Project site and a detailed hydraulic analysis. Data collected, hydraulic model input/output and scour calculations are presented in the appendices of this report. A narrative discussion of the problem statement, engineering methods, and the conclusions of the hydraulic study follows.

2.0 Project Description

The culvert is located on Chestnut Street immediately south of the intersection of Route 62 in the town of North Reading, Middlesex County, Massachusetts **(Figure 2-1).**

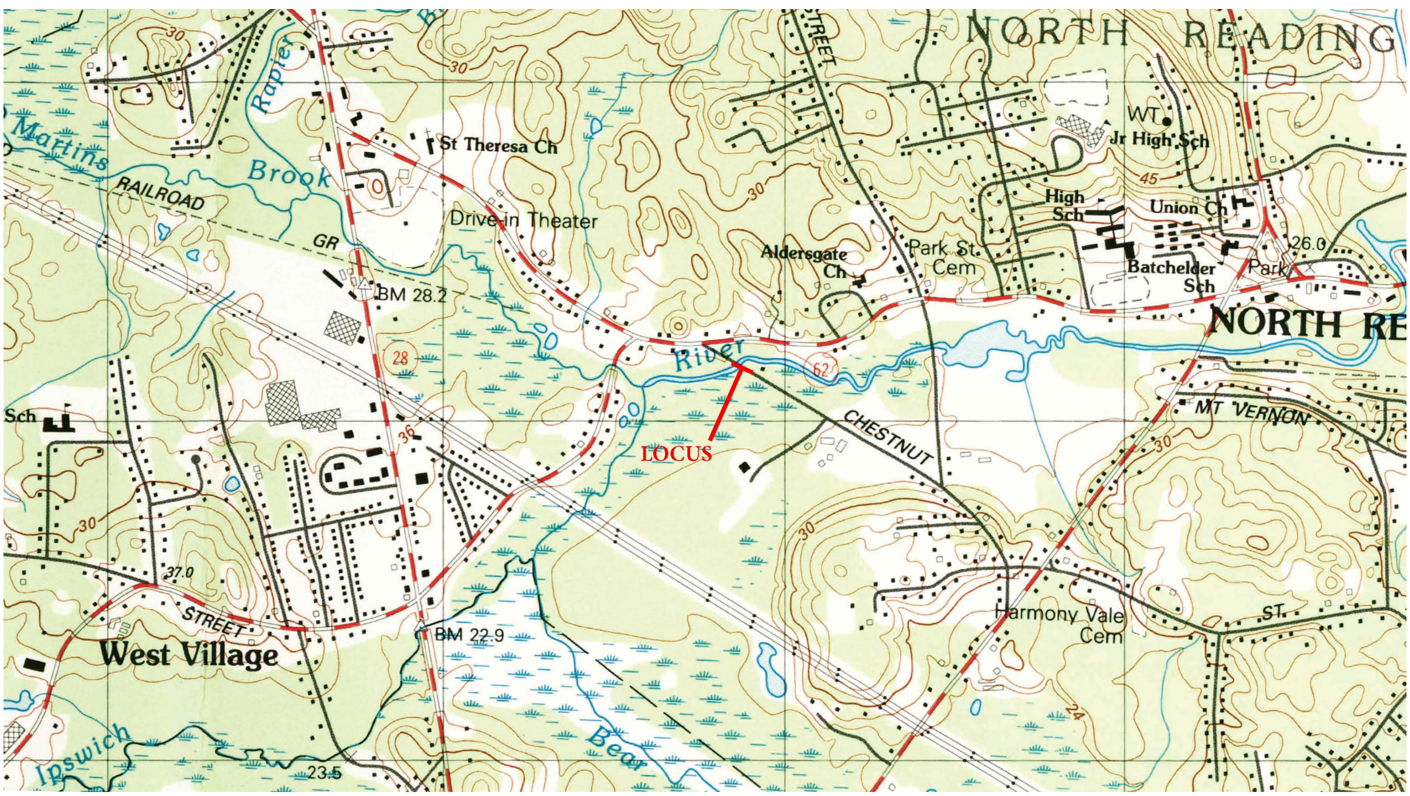


Figure 2-1: Culvert Location

2.1 Existing Structure

The subject culvert is located on Chestnut Street in the Town of North Reading, Middlesex County, Massachusetts located largely within the Chestnut Street layout adjacent to the intersection with Route 62. The Massachusetts State Plane Coordinates (NAD83-feet) for the center of the culvert are N 3,033,678/E 764,737 **(Appendix 7.1.1)**. The culvert has a MassDOT designation of N18003-2D4-MUN-NBI and the date of construction is 1967. The culvert consists of two 9.2' high x 13.7' wide corrugated steel structures that are about 60'long (start flared end to end flared end). The inlet and outlet consist of flared ends mitered to the slope.

The roadway is a two-lane Urban Collector roadway approximately 26' wide with bituminous berm in the area of the culvert. There is approximately 2' of cover over the existing culvert at the crown of the roadway. The runoff from the roadway sheet flows off the pavement on the sides of the road where it then flows into the river

.

Figure 2-2: Existing Culvert

2.1.1 Crossed Waterway at the Culvert Location

The Ipswich River flows from its source at the confluence of Maple Meadows Brook and Lubbers Brook toward the point where it flows under Chestnut Street, which is about 3.1 miles east of that point. The river continues to flow east and north toward Middleton. The upstream drainage area is about 37.1 square miles **Figure 2-3**. According to the USGS map, the stream is perennial (**Appendix 7.1.1**).

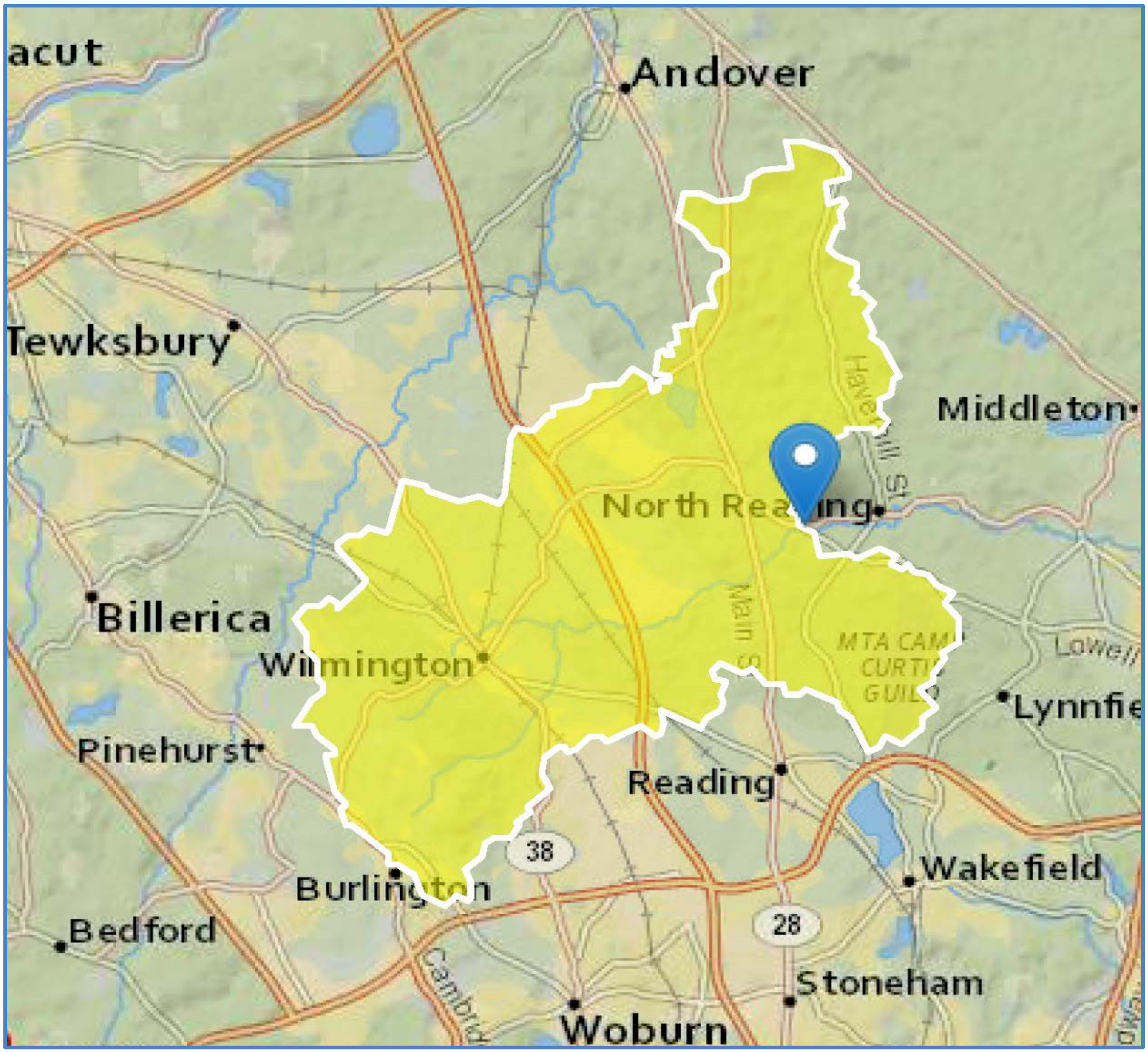


Figure 2-3: Drainage Area at Bridge Crossing

2.1.2 Highway Conveyed

Chestnut Street is classified as an Urban Collector road which conveys approximately 4,283 vehicle trips per day. It is two-lane and approximately 26' wide with bituminous berm in the area of the culvert.

2.1.3 Land Use in the Vicinity of the Bridge

Land use near the bridge is a mix of forest, residential, open land and commercial (**Figure 2-4**).

Figure 2-4: Land Use at the Bridge Location

2.1.4 Special Site Considerations

The existing culvert is located within the National Flood Insurance Program (NFIP) Special Flood Hazard Area (SFHA) Zone AE as shown on the 2010 Flood Insurance Rate Map (FIRM) Panel No. 25017C0303E (**Appendix 7.1.2 and Figure 2-5**).

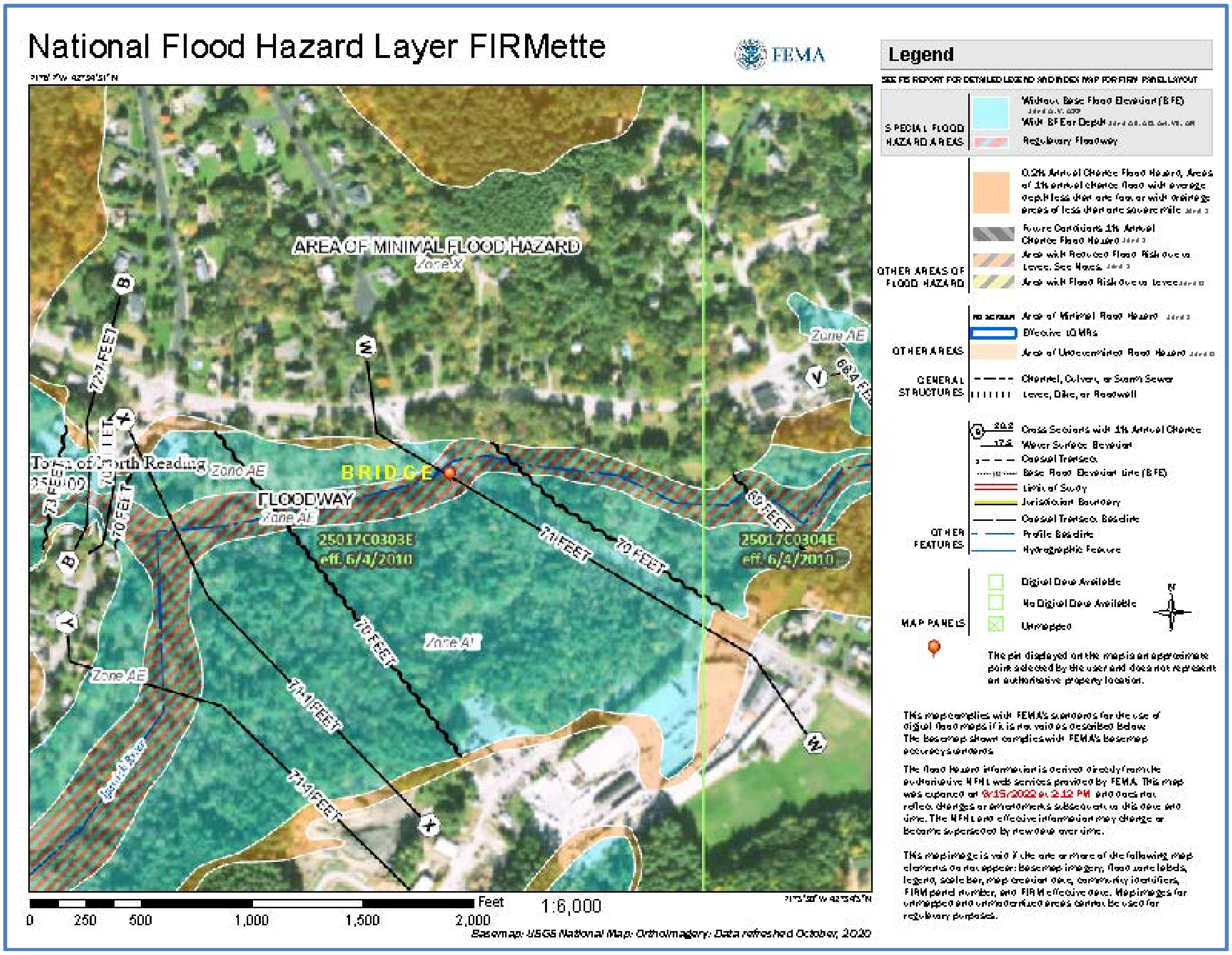


Figure 2-5: Flood Insurance Rate Map

2.2 Proposed Action

The project objective is to upgrade the existing culvert to the maximum feasible extent to comply with the MassDOT LRFD Bridge Manual (**Reference 3**) and with the Massachusetts Stream Crossing Standard (**Reference 7**). The proposed action is the construction of a bridge with U-wingwalls in the same general location and alignment with the existing culverts. **Figures 2-6 to 2-7** show the proposed cross sections of the alternatives.

- Alternative 1 – 48’ wide span x 10’ maximum clear opening
- Alternative 2 – 34’ wide span x 10’maximum clear opening

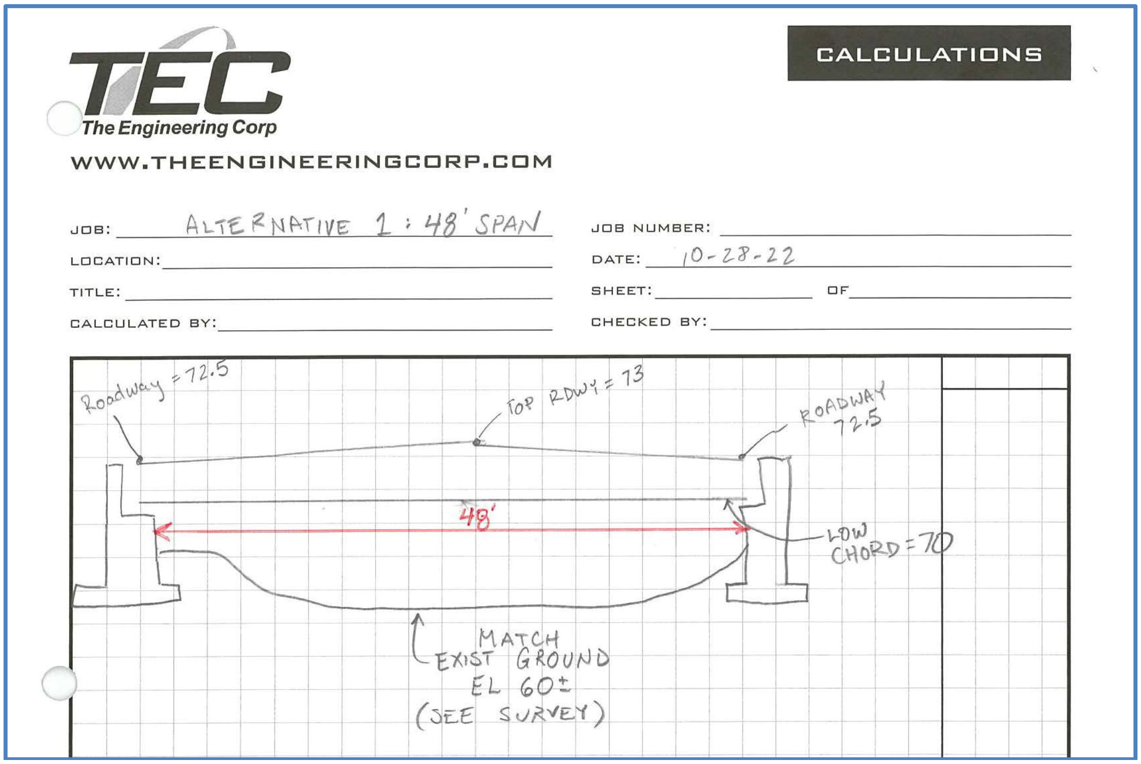


Figure 2-6: Alternative 1: 48' Span

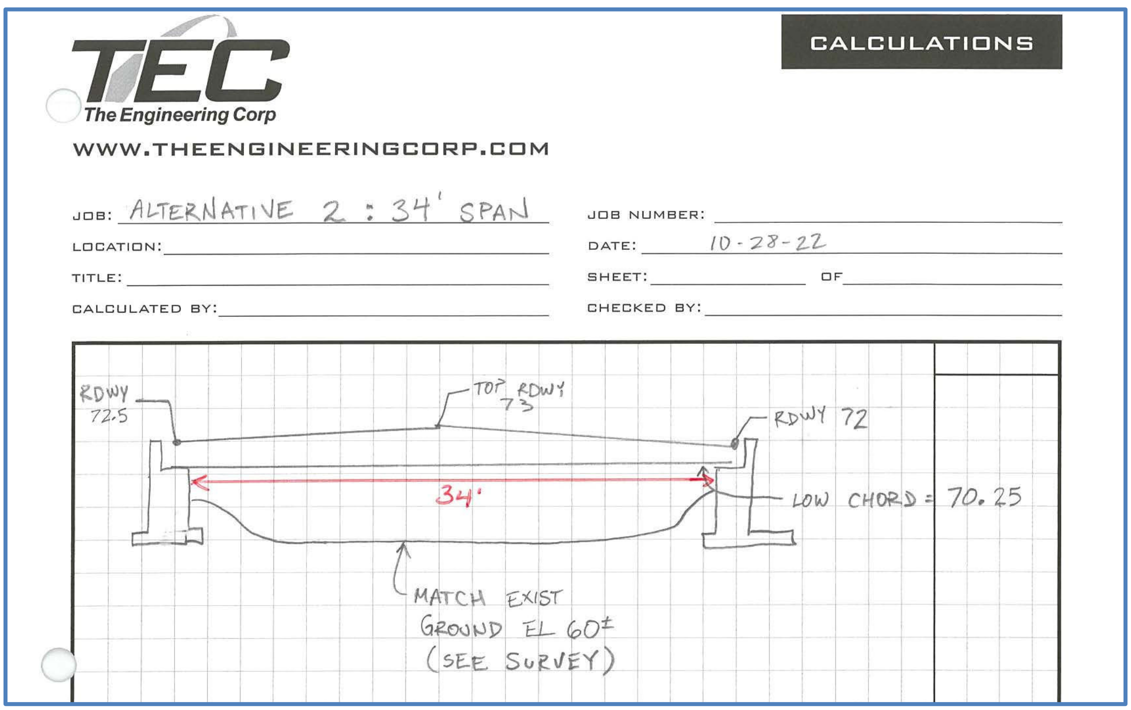


Figure 2-7: Alternative 2: 34' Span

3.0 Data Collection

The following references and reports on the study area were available and were used as guidance during the hydrologic and hydraulic model development and analysis:

- Middlesex County Flood Insurance Study (FIS) July 6, 2016 (**Reference 1**)
- Middlesex County Flood Insurance Rate Map (FIRM) No. 25017C0303E, June 4, 2010 **(Reference 2)**
- Scour Sediment Sampling Results (**Appendix 7.4.2**)
- Base plans prepared by Hancock Associates, September 8, 2022

4.0 Engineering Methods

Hydrologic and hydraulic analyses were conducted to estimate the peak design discharges and water surface elevations respectively at the culvert location. The following sections briefly describe the methodology.

4.1 Hydrologic Analysis

The objective of the hydrologic analysis was to establish the 10% (10-yr), 4% (25-yr), 2% (50-yr) and 1% (100-yr) annual probability event peak discharges for the Ipswich River at the Project site and to establish boundary conditions required for the hydraulic and scour analysis. The design flood frequency for an *Urban Collector* bridge is 10% (**Reference 3**). The stream's drainage area at the Project location was delineated using the USGS StreamStats Website (**Reference 11**); See **Section 2.1.1** and **Figure 2-3** for delineated area at the bridge.

The FEMA Engineering Library furnished the HEC-2 data used to develop the FIS for the Ipswich River (**Appendix 7.1.5).** The HEC-2 data determined the peak flood discharges for the 10% (10-yr), 2% (50-yr), 1% (100-yr), and 0.2% (500-yr) annual probability flood events **(Table 4-1).** The FIS data for the 1% annual probability flood event will be used for the no-rise analysis.

USGS gauge no. 01101500 **(Reference 4)** is located about 3.9 miles downstream of the of the subject bridge. The drainage area at this gauging station is 43.4 square miles and the contributing area at the subject bridge is 37.1 square miles. About 84 years of peak flow data from 1938 to 2021 is available at the gauge **(Appendix 7.2.2)**. This data will be used to determine the design flows for the bridge site through the use of a standard Log Pearson Type III annual flood frequency analysis of the gauge data using the PeakFQ software (**Reference 10).** Given the long period of record of the gauge data, the PeakFQ peak flows for the various return frequencies represent more accurate hydrologic conditions for the site and will be used for the proposed condition hydraulic and scour analyses. The gauged flow statistics were scaled down to the bridge location using the simple drainage area ratio method and using the methodology outlined in USGS Scientific Investigations Report 2016-5156, Magnitude of Flood Flows at Selected Annual Exceedance Probabilities for Streams in Massachusetts **(Reference 5).**

The FIS peak flows used in the no-rise analysis, the computed PeakFQ flows at USGS Stream Gauge 01101500, and the PeakFQ flows at the bridge site used in the design are detailed in **Table 4-1** and the hydrologic computations are in **Appendix 7.2.4**.

Table 4-1: Peak Flood Discharges

Annual Probability Flood Event	FIS Peak Flow (cfs)	PeakFQ Flow @ Site (cfs)	Peak FQ Flow @ USGS Stream Gauge 01101500 (cfs)
10% (10-year)	605	688	777
4% (25-year)	-	895	1,012
2% (50-year)	880	1,071	1,208
1% (100-year)	1,035	1,260	1,422

4.2 Hydraulic Analyses

The hydraulic analysis was conducted using the US Army Corps of Engineer (USACOE), Hydrologic Engineering Center, HEC-RAS version 6.2 River Analysis System (**Reference 12**). HEC-RAS is capable of calculating steady flow water surface profile computations, one- and two-dimensional unsteady flow simulation, movable boundary sediment transport computations and water quality analysis. For the purposes of this analysis, we will be using the one-dimensional, steady flow water surface profile module to calculate the water surface profiles for the existing condition and then develop a proposed upgraded design for the project site. Water surface profiles for 10%, 4%, 2% and 1% annual probability peak discharge events were developed in a manner consistent with the applicable NFIP base floodplain development performance standards. The datum used in all hydraulic models is NAVD 1988 and the datum conversion from NGVD 1929, which was used in the HEC-2 data, to NAVD 88 is -0.8'.

4.2.1 No-Rise and Existing Conditions Analyses

Because the existing structure spans an effective NFIP regulatory floodway it is necessary to develop a no-rise base flood elevation profile hydraulic analysis as outlined in the MassDOT LRFD Bridge Manual, Part 1, January 2020 Revision, paragraph 1.3.5 (**Reference 3)**. The goal is to demonstrate compliance with the applicable NFIP development standards as described in 44 CFR 60.3(d)(3) which states:

(3) The community shall prohibit encroachments, including fill, new construction, substantial improvements, and other development within the adopted regulatory floodway unless it has been demonstrated through hydrologic and hydraulic analyses performed in accordance with standard engineering practice that the proposed encroachment would not result in any increase in flood levels

within the community during the occurrence of the base flood discharge.

The FEMA FIS HEC-2 data for the encroachment analysis was received from the FEMA Engineering Library and was used in the analysis (**Appendix 7.1.5).**

4.2.2 Duplicative Effective Analysis

A duplicative effective analysis was conducted that involved uploading the currently effective model's input data received from FEMA into the HEC-RAS system. The design was calibrated to reproduce the currently effective BFE profile shown in the FIS within 0.5 feet. The reach domain was run between HEC-2 cross section 28189, which is about 926' upstream of the site, to cross section 25420, which is about 1,800' downstream of the site. There are two lettered cross sections within the project area and the duplicative effective model reproduced the current effective BFE for both cross sections to within 0.2 feet. Additional surveyed cross section data was input to represent the channel geometry more accurately, but no changes were made to the HEC-2 data **Figure 4-1**. The duplicative effective model as modified will be used as the existing conditions model. The FIS base flow listed in **Table 4-1** was used and a normal depth slope of 0.0015 was used as the reach boundary condition. A summary of the duplicative effective analysis is presented in **Table 4-2**

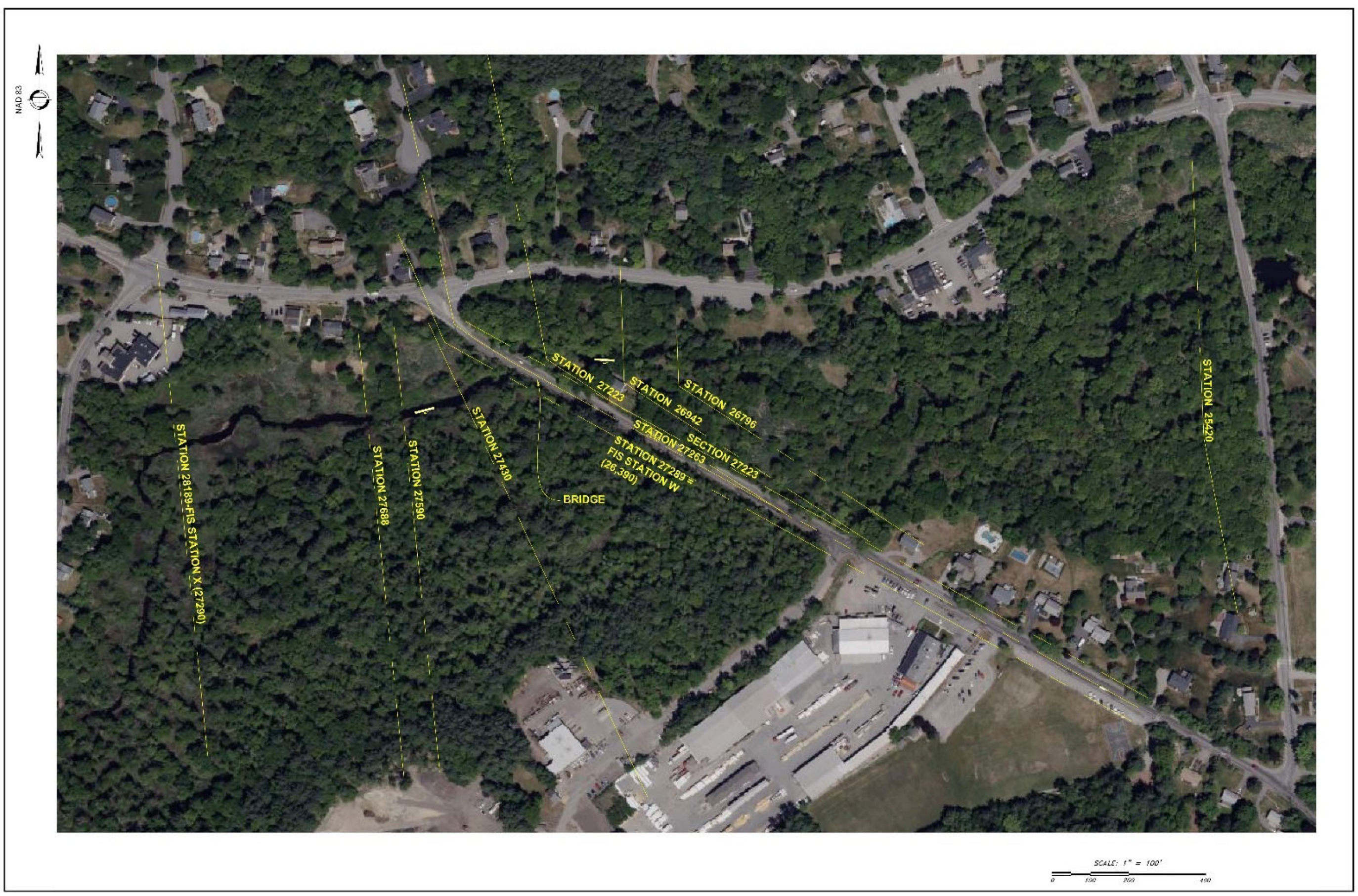


Figure 4-1: HEC-RAS Cross Section Layout Plan

Table 4-2: Summary of Duplicative Effective Model Results

HEC-2 Station	HEC-RAS Cross Section	FIS Cross Section	FIS BFE (ft, NAVD)	Duplicative Effective BFE (ft, NAVD)	Difference (ft)
27289	27289	W	70.9	70.9	0.0
28189	28189	X	71.2	71.0	-0.2

The duplicative effective model, which is also the existing conditions model, was used and run using HEC-RAS in a subcritical flow mode under the following two scenarios: (1) Using the FIS base flow and normal depth for boundary conditions for the no-rise analysis and; (2) Using the USGS PeakFQ derived flows and normal depth for boundary conditions for the Project design.

4.2.3 Proposed Condition Analysis

The proposed action is to replace the double culverts with a bridge and the alternatives described in **Section 2.2** were evaluated. The proposed condition models were developed after updating the existing culvert geometry with the proposed bridge geometry. All other model parameters remain the same as in the existing condition model. The proposed condition analysis was performed:

(1) To compare the effective existing condition model with the proposed model results using the FIS 1% probability event base flow for the no-rise analysis; and
(2) To evaluate the Project impact using the USGS PeakFQ design hydrology.

Proposed Condition No-Rise Analysis

For the no-rise analysis, the proposed model was analyzed with the FIS 1% frequency event base flow listed in **Table 4-1** and a normal depth slope = 0.0015 as the downstream boundary condition using one dimensional steady state HEC-RAS modeling. The model was run in a subcritical flow regime. **Table 4-2.1** shows the results of the no-rise analysis at each of the FIS and HEC-RAS cross sections.

Table 4-2.1: Comparison of Hydraulic Performance for BFE

HEC-RAS Cross Section	Description of Cross Section	Existing Water Surface Elevation (ft,NAVD)	Alternative 1 Proposed Water Surface Elevation (ft,NAVD)	Alternative 1 Project Impact (ft)	Alernative 2 Proposed Water Surface Elevation (ft,NAVD)	Alternative 2 Project Impact (ft)
28189	FIS X	71.0	69.0	-2.0	69.1	-1.9
27688	Survey	70.9	68.9	-2.0	69.0	-1.9
27590	Survey	70.9	68.9	-2.0	69.0	-1.9
27430	Survey	70.9	68.8	-2.1	69.0	-1.9
27303	Survey	70.9	68.8	-2.1	68.9	-2.0
27289	FIS W	70.9	68.5	-2.4	68.7	-2.2
Bridge						
27223	FIS	70.4	68.3	-2.1	68.3	-2.1
27173	FIS	68.4	68.4	0.0	68.4	0.0
26942	Survey	67.9	67.9	0.0	67.9	0.0
26796	Survey	67.8	67.8	0.0	67.8	0.0
25420	FIS	66.1	66.1	0.0	66.1	0.0

<u>Proposed Condition Design Flood Analysis</u>

As stated, all design flood simulations performed in HEC-RAS modeling were run in a subcritical flow mode and employed the USGS PeakFQ discharges listed in **Table 4-1.** The upstream and downstream boundary conditions were assumed to be normal depth. **Table 4-3** summarizes the hydraulic performance at the upstream cross section (HEC-RAS Cross Section 27289 & FIS Cross Section W) of the culvert for the existing condition and the proposed alternatives for the 1% frequency event. The water surface elevations for both alternatives are less than then existing conditions, but the average velocity increases for all conditions. The reason for this is that there is significant weir flow under existing conditions which increases the area of flow and decreases the average velocity. The alternatives both carry all the flow with no weir flow, and thus a lower area of flow and an increased velocity. The contracted velocity under the bridge for Alternative 1 and Alternative 2 is like the velocity found in Cross Section 27289 and downstream of the proposed bridge. There is a significant 50-70% decrease in velocity from the existing condition to the developed condition in Cross Section 27223 which is immediately downstream of the bridge.

Table 4-3: Summary of Hydraulic Performance Upstream of Culvert

Annual Probability Flood Event	Peak Flow (cfs)	Existing			Alternative 1			Alternative 2		
		WSEL (ft, NAVD)	Average Velocity (ft/sec)	Velocity in Structure (ft/sec)	WSEL (ft, NAVD)	Average Velocity (ft/sec)	Velocity in Structure (ft/sec)	WSEL (ft, NAVD)	Average Velocity (ft/sec)	Velocity in Structure (ft/sec)
10% (10-year)	688	70.3	0.8	0.4	67.7	3.4	3.0	67.8	3.3	3.8
4% (25-year)	895	70.7	0.9	0.5	68.2	4.0	3.5	68.3	3.9	4.5
2% (50-year)	1071	71.0	0.9	0.4	68.6	4.4	4.0	68.7	4.3	5.2
1% (100-year)	1260	71.1	1.0	0.5	68.9	4.9	4.4	69.1	4.8	5.8

Measurement at HEC-RAS Station 27289

The site has a Highway Functional Classification of Urban Collector and Table 1.3.4-1 of the MassDOT LRFD Manual (**Reference 3**) lists the hydraulic design flood as the 10% annual probability event which has been calculated as 688 cfs (**Table 4-1**). A comparison of the 1% (100-yr) design base flood elevations (BFE) between the existing and all proposed modeled cross sections is presented in **Table 4-4.**

Table 4-4: Comparison of Existing and Proposed BFEs for 10% Probability Design Flow

HEC-RAS Cross Section	Description of Cross Section	Existing Water Surface Elevation (ft,NAVD)	Alternative 1 Proposed Water Surface Elevation (ft,NAVD)	Alternative 1 Project Impact (ft)	Alernative 2 Proposed Water Surface Elevation (ft,NAVD)	Alternative 2 Project Impact (ft)
28189	FIS X	70.4	68.1	-2.3	68.1	-2.3
27688	Survey	70.3	68.0	-2.3	68.0	-2.3
27590	Survey	70.3	68.0	-2.3	68.0	-2.3
27430	Survey	70.3	67.9	-2.4	68.0	-2.3
27303	Survey	70.3	67.9	-2.4	68.0	-2.3
27289	FIS W	70.3	67.7	-2.6	67.8	-2.5
Bridge						
27223	FIS	69.4	67.6	-1.8	67.6	-1.8
27173	FIS	67.6	67.6	0.0	67.6	0.0
26942	Survey	67.3	67.3	0.0	67.3	0.0
26796	Survey	67.1	67.1	0.0	67.1	0.0
25420	FIS	64.2	64.2	0.0	64.2	0.0

The proposed stream WSEL will be the same, or less than, the existing WSEL at all cross sections. **Table 4-4** and **Appendix 7.3** list the results of the HEC-RAS modeling and WSEL profiles of the river.

4.2.4 Scour Safety and Stability Analysis

Scour potential at the crossing site was analyzed using the requirements set forth by MassDOT's LRFD Bridge Manual, section 1.3.3.5 (**Reference 3**) and using the guidelines by FHWA HEC-18, "*Evaluating Scour at Bridges"* (**Reference 6).** In accordance with Section 1.3.4 of LRFD Bridge Manual, for *Urban Collector* Highway Functional Classification, the river's 4% (25-year) and 2% (50-year) chance flood events were used as the scour design and scour check events respectively.

The design approach was to estimate long term aggradation/degradation, flood related contraction and local abutment scour depths for the 4% and 2% probability flood events. In this study the total abutment scour is calculated using National Cooperative Highway Research Program (NCHRP 24-20) method described in HEC-18 **(Reference 6)** contraction scour is included in the value so it is not added separately.

The hydraulic variables used for scour calculations were obtained from the HEC-RAS model results. The results were extracted from cross sections at the approach section and contracted section. As listed in **Section 3.0**, the soil data for scour calculations was obtained from the sampling analysis conducted as part of this project **Appendix 7.4.1**. No historical data was available to calculate scour due to long term aggradation and degradation. In both the scour design and check event analyses, it is assumed that the channel bed elevation will not degrade over the service life of the bridge. A summary of computed 4% and 2% annual chance flood scour depths is presented in **Table 4-5.** See **Appendix 7-4** for the detailed scour calculations.

Table 4-5: Summary of Calculated Scour

Alternative	Annual Probability Event (%)	Total Abutment Scour (ft)
1	4	1.3
	2	1.4
2	4	3.2
	2	3.8

4.2.5 DEP Stream Crossing Standards

The DEP Stream Crossing Standards analyze a proposed crossing on a number of criteria that fall under the rubric of General Standard or Optimum Standard. The General Standard is typically reserved for repairs or replacements to existing structures. Alternative 1 will meet all of the General and Optimum Standards and Alternative 2 will meet the same except for the Crossing Span. See **Table 4-6** for a summary of the criteria.

Table 4-6: DEP Stream Crossing Standards

Standard	General Standard	Optimum Standard	Alternative #1	Alternative #2
1. Type of Crossing	Spans strongly preferred	same	Bridge Span	Bridge Span
2. Embedment	Culverts embedded 2'	same	Embedded min 2'	Embedded min 2'
3. Crossing Span	Spans channel width min of 1.2 bankfull width	Spans min of 1.2 bankfull with sufficient headroom to provide dry passage of wildlife	1.2 bankfull width w/9'+/- headroom	0.85 bankfull width w/9'+/- headroom
4. Opennes	Openness ratio of 0.82. Crossing should be wide and high relative to length.	Openness ratio of 1.64 and min height of 6'. If significant conditions reduce wildlife passage maintain min height of 8' and openness ratio of 2.64	Openness ratio of 9.0 w/9'+/- height	Openness ratio of 7.3 w/ 9'+/- height
5. Substrate	Natural bottom	same	Natural bottom	Natural bottom
6. Water Depth & Velocity	Comparable to found in natural channel	same	Water depth and velocity are comparable to natural channel	Water depth and velocity are comparable to natural channel

5.0 Conclusions & Recommendations

5.1 Conclusions

1. The Project hydraulic model predicts that the existing culvert will not convey the 10% annual probability design flood event.
2. The Project hydraulic model predicts that either alternative will safely convey the 10% annual probability design flood event with 2' of freeboard.
3. Both alternatives will convey the entire storm and will not have weir flow over the roadway during the 1% probability flood event.
4. Alternative 1 will meet all the DEP Stream Crossing General Standards
5. Alternative 2 will not meet the Crossing Span standard of the DEP Stream Crossing Standards.

5.2 Recommendations

6. The information in **Table 5-1** for the recommended alternative should be presented within the Hydraulic Data Tables in the General Notes of the Construction Plan sets.
7. The grades that will exist at the abutment and wingwalls should be stabilized with flexible revetments consisting of MassDOT Standard Specification M2.02.0 Riprap over a composite filter medium consisting of a layer of MassDOT Standard Specification M2.01.1, crushed stone placed over an appropriate MassDOT Standard Specification M9.50.0 Geotextile Fabric membrane.
8. The calculated 4% (25-year) probability flood event total scour depth presented in **Table 5-1** for Alternative 1 should be considered for use as a bridge foundation condition in LRFD strength and service limit state foundation stability determination. Similarly, the calculated 2% (50-yr) probability flood event scour depth should be considered for use as a bridge foundation condition in the LRFD extreme event limit state foundation stability determination. The design engineer should be cognizant that the proposed culvert substructure will meet the foundation scour stability requirements set forth in MassDOT Bridge LRFD Manual (**Reference 3**), Section 3.2.10, and presented below.

For new bridges or full bridge replacements, the substructures shall be designed to meet the requirements of Paragraphs 3.2.10.2 and 3.9.10.3 for the calculated design and check scour without using scour countermeasures.

9. The design engineer should specify that the material to be placed in the stream under the bridge meets the gradation of the existing stream bed (**Appendix 7.4.1**).

Table 5-1: Hydraulic Design Data (Existing & Proposed Conditions)

Hydraulic Design Data	**Existing**	**Alternative 1**	**Alternative 2**
Drainage Area:	37.1 Square miles		
Design Flood Discharge:	688 Cubic Feet Per Second		
Design Flood Annual Probability (Return Frequency):	10% (10 Years)		
Design Flood Velocity in Structure (Feet Per Second):	0.4 Ft/Sec	3.0 Ft/Sec	3.8 Ft/Sec
Design Flood Elevation Upstream (Feet-NAVD):	70.3 Feet	67.7 Feet	67.8 Feet

Base (100- YEAR) Flood Data	**Existing**	**Alternative 1**	**Alternative 2**
Base Flood Discharge:	1,260 Cubic Feet per Second		
Base Flood Elevation (Feet-NAVD):	71.1 Feet	68.9 Feet	69.1 Feet

Design and Check Scour Data	**Alternative 1**	**Alternative 2**
Scour Design Flood Annual Probability (Return Frequency):	4% (25 Years)	
Design Flood Total Abutment Scour Depth:	1.3 Feet	3.2 Feet
Scour Check Flood Annual Probability (Return Frequency):	2% (50 Years)	
Check Flood Total Abutment Scour Depth:	1.4 Feet	3.8 Feet

Flood of Record	
Discharge:	Not Known
Frequency (If Known):	Not Known
Maximum Elevation:	Not Known
Date:	Not Known
History of Ice Floes:	None documented
Evidence of Scour and Erosion:	None documented

6.0 References

6.1 Data Sources

Reference No.	Title
1	Middlesex County Flood Insurance Study (FIS) Panel No. 25017C0303E, effective date July 6, 2016
2	Middlesex County Flood Insurance Rate Map (FIRM) No. 25017C0303E, June 4, 2010
3	MassDOT LRFD Bridge Manual, January 2020 Revision
4	USGS Gauge Data from Station 01101500 – Ipswich River @ South Middleton, MA
5	USGS Scientific Investigations Report 2016-5156, Magnitude of Flood Flows at Selected Annual Exceedance Probabilities for Streams in Massachusetts; Zarriello, P.J., 2017
6	US Department of Transportation Federal Highway Administration Hydraulic Engineering Circular No. 18 "Evaluating Scour at Bridges", Fifth Edition, April 2012
7	MassDOT "Design of Bridges and Culverts for Wildlife Passage at Freshwater Streams" December, 2010
8	MassDOT Culvert Inspection Report, File No. N-18-003, February 16, 2022 & May 24, 2022
9	USGS Gauge Data from Station 01101500 – Ipswich River @ South Middleton, MA

6.2 Data Applications

10	Peak FQ v 7.1, Annual Flood Frequency Analysis Using USGS Bulletin 17C Guidelines
11	United States Geological Survey (USGS) National Streamflow Statistics (StreamStats), Version 4.10.11
12	US Army Corps of Engineer (USACOE), Hydrologic Engineering Center, HEC-RAS River Analysis System, Version 6.2 March, 2022

7.0 Appendix

7.1 FEMA FIS & USGS Documents

7.1.1 Extract of USGS Reading Quadrangle
7.1.2 FEMA Firmette No. 25017C0303E, July 4, 2010
7.1.3 Floodway Data
7.1.4 Flood Profile
7.1.5 HEC-2 Data

7.2 Hydrologic Analyses

7.2.1 7.2.1 Drainage Area Using USGS Streamstats
7.2.2 USGS Gauging Station Data for Gauge No. 01101500
7.2.3 PeakFQ Report
7.2.4 Hydrologic Calculations

7.3 Hydraulic Analyses

7.3.1 Existing Conditions – FIS Flow
7.3.2 Existing Conditions – USGS PeakFQ Flows
7.3.3 Alternative 1 (48' Span) – FIS Flow
7.3.4 Alternative 1 (48' Span) – USGS PeakFQ Flows
7.3.5 Alternative 2 (34' Span) – FIS Flow
7.3.6 Alternative 2 (34' Span) – USGS PeakFQ Flows

7.4 Scour Calculations

7.5.1 Scour Sediment Sampling Results
7.5.2 Scour Calculations

7.1 FEMA FIS & USGS Documents

7.1.1 Extract of USGS Reading Quadrangle
7.1.2 FEMA Firmette No. 25017C0303E, July 4, 2010
7.1.3 Floodway Data
7.1.4 Flood Profile
7.1.5 HEC-2 Data

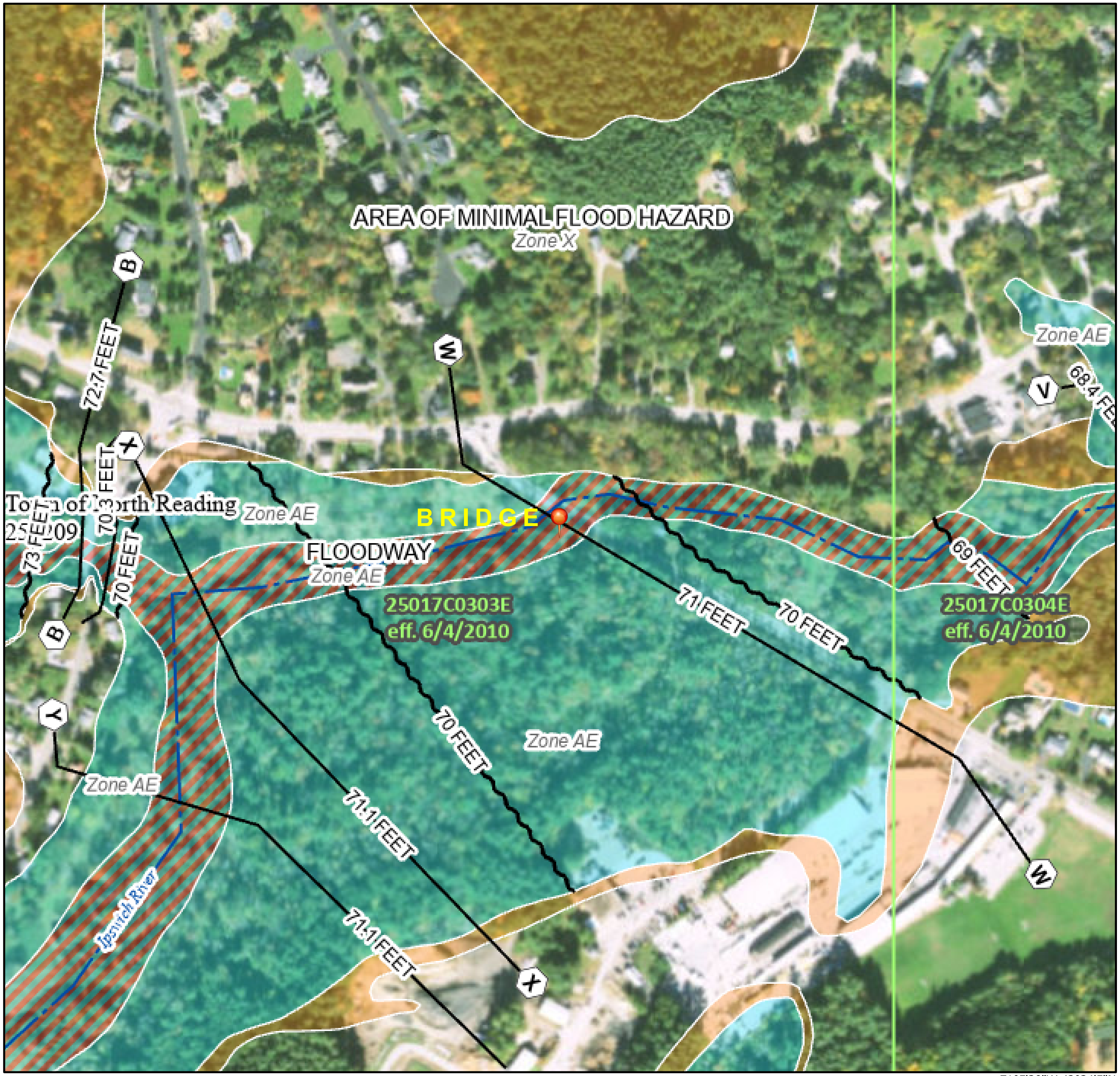
BAY COLONY GROUP, INC.
FOUR SCHOOL STREET
FOXBOROUGH, MA 02035
(508) 543-3939

USGS EXTRACT
IPSWICH RIVER @ CHESTNUT STREET
NORTH READING, MA
READING QUADRANGLE
SCALE: 1"= 1000'

National Flood Hazard Layer FIRMette

FEMA

71°6'7"W 42°34'31"N



71°5'30"W 42°34'5"N

0 250 500 1,000 1,500 2,000 Feet

1:6,000

Basemap: USGS National Map: Orthoimagery: Data refreshed October, 2020

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- 20.2 / 17.5 Cross Sections with 1% Annual Chance Water Surface Elevation
- 8 Coastal Transect
- 513 Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

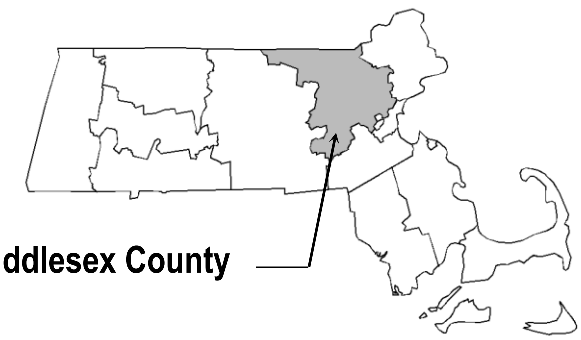
The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 9/15/2022 at 2:12 PM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

FLOOD INSURANCE STUDY

VOLUME 1 OF 8

MIDDLESEX COUNTY, MASSACHUSETTS
(ALL JURISDICTIONS)



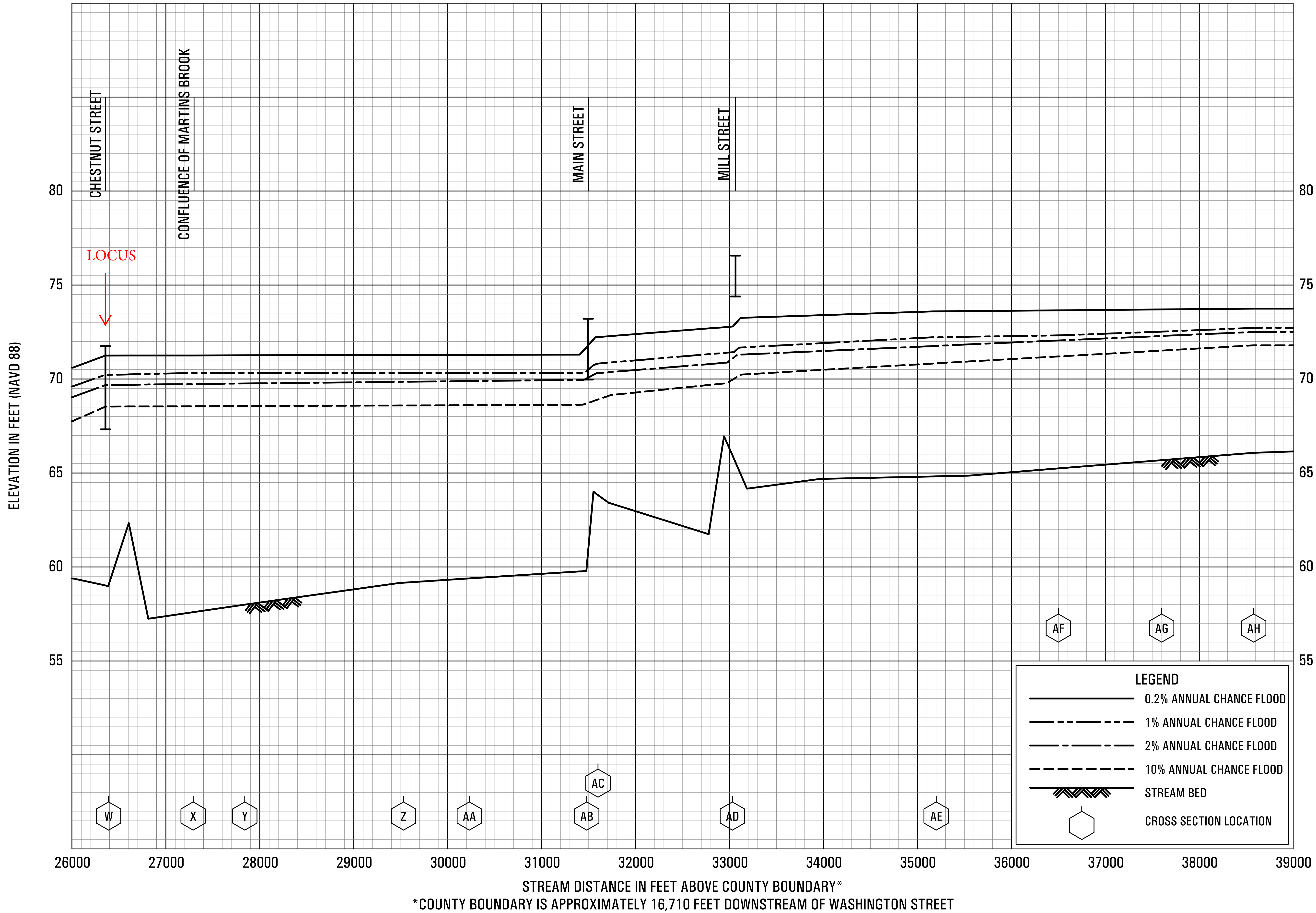
COMMUNITY NAME	COMMUNITY NUMBER
ACTON, TOWN OF	250176
ARLINGTON, TOWN OF	250177
ASHBY, TOWN OF	250178
ASHLAND, TOWN OF	250179
AYER, TOWN OF	250180
BEDFORD, TOWN OF	255209
BELMONT, TOWN OF	250182
BILLERICA, TOWN OF	250183
BOXBOROUGH, TOWN OF	250184
BURLINGTON, TOWN OF	250185
CAMBRIDGE, CITY OF	250186
CARLISLE, TOWN OF	250187
CHELMSFORD, TOWN OF	250188
CONCORD, TOWN OF	250189
DRACUT, TOWN OF	250190
DUNSTABLE, TOWN OF	250191
EVERETT, CITY OF	250192
FRAMINGHAM, TOWN OF	250193
GROTON, TOWN OF	250194
HOLLISTON, TOWN OF	250195
HOPKINTON, TOWN OF	250196
HUDSON, TOWN OF	250197
LEXINGTON, TOWN OF	250198
LINCOLN, TOWN OF	250199
LITTLETON, TOWN OF	250200
LOWELL, CITY OF	250201
MALDEN, CITY OF	250202
MARLBOROUGH, CITY OF	250203
MAYNARD, TOWN OF	250204
MEDFORD, CITY OF	250205

COMMUNITY NAME	COMMUNITY NUMBER
MELROSE, CITY OF	250206
NATICK, TOWN OF	250207
NEWTON, CITY OF	250208
NORTH READING, TOWN OF	250209
PEPPERELL, TOWN OF	250210
READING, TOWN OF	250211
SHERBORN, TOWN OF	250212
SHIRLEY, TOWN OF	250213
SOMERVILLE, CITY OF	250214
STONEHAM, TOWN OF	250215
STOW, TOWN OF	250216
SUDBURY, TOWN OF	250217
TEWKSBURY, TOWN OF	250218
TOWNSEND, TOWN OF	250219
TYNGSBOROUGH, TOWN OF	250220
WAKEFIELD, TOWN OF	250221
WALTHAM, CITY OF	250222
WATERTOWN, TOWN OF	250223
WAYLAND, TOWN OF	250224
WESTFORD, TOWN OF	250225
WESTON, TOWN OF	250226
WILMINGTON, TOWN OF	250227
WINCHESTER, TOWN OF	250228
WOBURN, CITY OF	250229

REVISED:
July 6, 2016

Federal Emergency Management Agency

FLOOD INSURANCE STUDY NUMBER
25017CV001C



FLOOD PROFILES

IPSWICH RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

MIDDLESEX COUNTY, MA
(ALL JURISDICTIONS)

267P

FLOODING SOURCE		FLOODWAY			BASE FLOOD WATER-SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
Ipswich River								
A	0	375/225[2]	1,925	0.5	59.6	59.6	59.6	0.0
B	600	70/35[2]	345	3.0	59.6	59.6	59.6	0.0
C	1,900	60/30[2]	380	2.7	60.2	60.2	60.6	0.4
D	3,945	75/45[2]	510	2.0	60.9	60.9	61.5	0.6
E	4,055	55/30[2]	370	2.8	61.1	61.1	61.6	0.5
F	4,915	80/40[2]	590	1.8	61.4	61.4	62.0	0.6
G	4,975	50/25[2]	410	2.5	61.6	61.6	62.1	0.5
H	6,925	45/25[2]	420	2.5	61.9	61.9	62.8	0.9
I	8,965	100/50[2]	675	2.4	62.2	62.2	62.8	0.6
J	14,065	100	675	1.8	62.6	62.6	63.3	0.7
K	16,670	94	455	2.8	63.0	63.0	63.8	0.8
L	16,770	60	475	2.2	63.1	63.1	63.8	0.7
M	17,490	60	400	2.6	63.4	63.4	63.8	0.4
N	18,250	50	315	3.3	64.0	64.0	64.3	0.3
O	18,360	50	325	3.2	64.7	64.7	64.9	0.2
P	20,880	40	330	3.1	66.7	66.7	66.9	0.2
Q	20,975	65	420	2.5	66.8	66.8	67.0	0.2
R	21,875	265	1,320	1.7	67.0	67.0	67.3	0.3
S	23,475	245	2,150	0.5	67.1	67.1	67.3	0.2
T	23,990	120	700	1.5	67.1	67.1	67.3	0.2
U	24,110	135	844	1.2	67.5	67.5	68.5	1.0
V	24,450	41	247	4.2	67.6	67.6	68.6	1.0
W	26,390	150	1,073	1.0	70.2	70.2	70.9	0.7
X	27,290	200	1,715	0.6	70.3	70.3	71.2	0.9
Y	27,840	200	1,558	0.3	70.3	70.3	71.2	0.9
Z	29,530	200	1,292	0.4	70.3	70.3	71.2	0.9

[1] Feet above county boundary, county boundary is approximately 16,710 feet downstream of Washington Street
[2] Width/width within county

TABLE 12

FEDERAL EMERGENCY MANAGEMENT AGENCY

MIDDLESEX COUNTY, MA
(ALL JURISDICTIONS)

FLOODWAY DATA

IPSWICH RIVER

FEMA Engineering Library
Digitized Data Index

CID:250211

Community:READING, TOWN OF (MIDDLESEX COUNTY, MASSACHUSETTS)

0507866

County:MIDDLESEX COUNTY

State:MASSACHUSETTS

Case Number:

Effective Date:

Description:1. Study

Contents:!09. Engineering Analysis: Hydraulics (riverine, stillwater, LDS)

Revision Status:

Flooding Source(s):IPSWICH RIVER

Notes:HEC-2 REVISION

Scanned by:

Scan Date:

QC Staff:

QC Date:

```
                                                                                THIS RUN EXECUTED 08/01/79  14.04.41
*****************************************
  HEC2 RELEASE DATED NOV 76 UPDATED  AUG1977
  ERROR CORR -  01,02
  MODIFICATION -  50,51,52,53
*****************************************

T1    FLOOD INSURANCE STUDY       READING,MASS
T2          IPSWICH RIVER -  REVISION
T3          100 YEAR NATURAL

J1   ICHECK      INQ       NINV      IDIR      STRT      METRIC      HVINS      Q        WSEL      FQ
        0.        4.        0.        0.   0.0          0.0         0.0      0.     68.250     0.0

J2   NPROF      IPLOT     PRFVS     XSECV     XSECH      FN        ALLDC      IBW      CHNIM     ITRACE
      1.000      0.0     -1.000      0.0       0.0       0.0        0.0       0.0       0.0       0.0

J3   VARIABLE CODES FOR SUMMARY PRINTOUT
     38.000    39.000    40.000    41.000    42.000    43.000     1.000     2.000     3.000    34.000

     21.000    22.000    26.000     0.0      38.000     1.000    50.000    61.000    51.000    53.000

     27.000     4.000    28.000    54.000    13.000    14.000    15.000   200.000     0.0       0.0
NC        0.120      0.120      0.065      0.300      0.500      0.0        0.0        0.0        0.0        0.0
QT        5.000    605.000    880.000   1035.000   1440.000   1035.000      0.0        0.0        0.0        0.0
ET        0.0        0.0        0.0        0.0        0.0        9.100      0.0        0.0      336.000    471.000

X1    25011.000     13.000    398.000    471.000     50.000     50.000     50.000      0.0        0.0        0.0
GR       75.000      0.0       70.000     65.000     64.800    355.000     62.800    398.000     62.500    425.000
GR       61.000    444.000     60.300    446.000     59.900    456.000     60.800    459.000     65.600    471.000
GR       65.000    491.000     65.000    580.000     74.000    590.000      0.0        0.0        0.0        0.0
ET        0.0        0.0        0.0        0.0        0.0        9.100      0.0        0.0      755.000    835.000

X1    25300.000     15.000    780.000    835.000    500.000    110.000    289.000      0.0        0.0        0.0
GR       75.000      0.0       70.000    350.000     65.000    780.000     61.000    790.000     58.000    795.000
GR       58.000    800.000     59.800    805.000     60.400    810.000     61.200    819.000     62.700    824.000
GR       65.000    835.000     70.000   1015.000     70.000   1100.000     70.000   1130.000     73.500   1160.000
NC        0.0        0.0        0.180      0.600      0.800      0.0        0.0        0.0        0.0        0.0
ET        0.0        0.0        0.0        0.0        0.0        9.100      0.0        0.0      688.000    729.000

X1    25350.000     27.000    687.000    730.000     50.000     50.000     50.000      0.0        0.0        0.0
GR       74.900      5.000     74.000    405.000     72.200    455.000     72.200    655.000     71.200    685.000
GR       72.300    687.000     68.300    688.000     64.500    690.000     62.000    692.000     60.000    693.000
GR       62.700    694.000     68.000    694.100     68.000    700.000     60.500    700.100     62.700    701.000
GR       62.000    728.000     68.000    729.000     72.500    730.000     70.500    732.000     70.400    755.000
GR       70.600    810.000     72.000    980.000     70.000    982.000     68.000    983.000     70.000    984.000
GR       72.000    986.000     73.500   1100.000      0.0        0.0        0.0        0.0        0.0        0.0
ET        0.0        0.0        0.0        0.0        0.0        9.100      0.0        0.0      688.000    729.000
```

X1	25380.000	0.0	0.0	0.0	30.000	30.000	30.000	0.0	0.0	0.0
NC	0.120	0.120	0.065	0.300	0.500	0.0	0.0	0.0	0.0	0.0
QT	5.000	605.000	880.000	1035.000	1440.000	1035.000	0.0	0.0	0.0	0.0
ET	0.0	0.0	0.0	0.0	0.0	9.100	0.0	0.0	700.000	800.000
X1	25420.000	15.000	730.000	775.000	40.000	40.000	40.000	0.0	0.0	0.0
GR	75.000	40.000	70.000	365.000	70.000	545.000	65.000	645.000	64.200	725.000
GR	65.000	730.000	60.200	740.000	60.800	753.000	60.900	758.000	60.200	768.000
GR	61.800	770.000	64.000	775.000	65.000	840.000	70.000	1155.000	73.500	1200.000
ET	0.0	0.0	0.0	0.0	0.0	9.100	0.0	0.0	250.000	350.000
X1	27173.000	19.000	250.000	295.000	1200.000	1200.000	1753.000	0.0	0.0	0.0
GR	78.000	0.0	75.000	30.000	66.200	240.000	66.000	250.000	62.800	255.000
GR	59.500	265.000	60.800	270.000	61.300	275.000	62.800	275.100	65.900	285.000
GR	67.300	295.000	66.900	305.000	65.900	350.000	70.000	550.000	68.000	650.000
GR	70.000	770.000	68.000	1070.000	70.000	1450.000	74.500	2250.000	0.0	0.0
NC	0.150	0.150	0.0	0.600	0.800	0.0	0.0	0.0	0.0	0.0
ET	0.0	0.0	0.0	0.0	0.0	9.100	0.0	0.0	818.000	1707.000
X1	27223.000	30.000	818.000	850.200	50.000	50.000	50.000	0.0	0.0	0.0
X3	10.000	0.0	0.0	0.0	0.0	0.0	0.0	71.800	69.500	0.0
GR	78.000	476.000	74.000	576.000	72.000	676.000	71.800	726.000	66.000	776.000
GR	63.000	818.000	63.000	820.000	63.000	825.100	63.000	830.200	63.000	832.200
GR	62.900	836.000	62.900	838.000	62.900	843.100	62.900	848.200	62.900	850.200
GR	66.000	870.000	71.100	970.000	71.000	1070.000	70.000	1270.000	70.700	1420.000
GR	70.300	1470.000	70.700	1570.000	69.700	1670.000	69.900	1770.000	70.600	1870.000
GR	70.900	1970.000	70.500	2070.000	72.300	2170.000	72.800	2270.000	75.000	2670.000
NC	0.0	0.0	0.025	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ET	0.0	0.0	0.0	0.0	0.0	9.100	0.0	0.0	818.000	1740.000
SB	0.0	1.560	2.600	0.0	28.200	0.0	162.000	0.0	62.900	62.900
X1	27263.000	0.0	0.0	0.0	40.000	40.000	40.000	0.0	0.0	0.0
X2	0.0	0.0	1.000	70.600	69.600	0.0	0.0	0.0	0.0	0.0
X3	10.000	0.0	0.0	0.0	0.0	0.0	0.0	71.800	69.700	0.0
BT	30.000	476.000	78.000	78.000	576.000	74.000	74.000	676.000	72.000	72.000
BT	726.000	71.800	71.800	776.000	72.100	72.100	818.000	72.300	63.000	820.000
BT	72.300	68.000	825.100	72.300	70.600	830.200	72.300	68.000	832.200	72.200
BT	63.000	836.000	72.200	62.900	838.000	72.200	68.000	843.100	72.200	70.300
BT	848.200	72.200	68.000	850.200	72.200	62.900	870.000	72.200	72.200	970.000
BT	71.100	71.100	1070.000	71.000	71.000	1270.000	70.000	70.000	1420.000	70.700
BT	70.700	1470.000	70.300	70.300	1570.000	70.700	70.700	1670.000	69.700	69.700
BT	1770.000	69.900	69.900	1870.000	70.600	70.600	1970.000	70.900	70.900	2070.000
BT	70.500	70.500	2170.000	72.300	72.300	2270.000	72.800	72.800	2670.000	75.000
BT	75.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NC	0.120	0.120	0.065	0.300	0.500	0.0	0.0	0.0	0.0	0.0
ET	0.0	0.0	0.0	0.0	0.0	9.100	0.0	0.0	800.000	950.000
X1	27289.000	19.000	825.000	850.000	26.000	26.000	26.000	0.0	0.0	0.0
GR	75.000	0.0	70.000	610.000	66.000	780.000	65.900	800.000	65.600	825.000
GR	63.800	830.000	59.000	835.000	58.000	840.000	60.000	845.000	63.200	845.000
GR	65.800	850.000	65.200	870.000	64.600	890.000	64.800	930.000	69.800	1000.000
GR	70.000	1200.000	69.500	1810.000	70.000	2170.000	74.000	2400.000	0.0	0.0
NC	0.0	0.0	0.0	0.100	0.300	0.0	0.0	0.0	0.0	0.0
ET	0.0	0.0	0.0	0.0	0.0	9.100	0.0	0.0	450.000	650.000
X1	28189.000	13.000	490.000	530.000	800.000	1000.000	900.000	0.0	0.0	0.0
GR	75.000	0.0	73.200	130.000	70.000	235.000	66.000	400.000	65.000	490.000
GR	58.500	495.000	58.500	525.000	64.000	530.000	64.000	595.000	65.000	780.000
GR	68.500	1150.000	70.000	1500.000	75.000	1580.000	0.0	0.0	0.0	0.0
QT	5.000	370.000	535.000	625.000	875.000	535.000	0.0	0.0	0.0	0.0
ET	0.0	0.0	0.0	0.0	0.0	9.100	0.0	0.0	340.000	540.000

X-section "W" (marked beside the block beginning X1 27289.000)

X-section "X" (marked beside the block beginning X1 28189.000)

FLOODWAY DATA,   100 YEAR NATURAL
PROFILE NO. 2

STATION	------- FLOODWAY ------- WIDTH (FT)	SECTION AREA	MEAN VELOCITY	WATER SURFACE ELEVATION WITH FLOODWAY	WITHOUT FLOODWAY	DIFFERENCE
25011.000	135.	844.	1.2	69.3	68.3	1.0
25300.000	80.	550.	1.9	69.4	68.4	1.0
25350.000	41.	247.	4.2	69.4	68.4	1.0
25380.000	41.	296.	3.5	70.6	70.2	0.4
25420.000	100.	792.	1.3	70.9	70.5	0.4
27173.000	100.	652.	1.6	71.6	70.6	1.0
27223.000	889.	1622.	0.6	71.6	70.6	1.0
27263.000	922.	1472.	0.7	71.7	70.7	1.0
27289.000	150.	1073.	1.0	71.7	71.0	0.7
28189.000	200.	1715.	0.6	72.0	71.1	0.9
28739.000	200.	1558.	0.3	72.0	71.1	0.9
30430.000	200.	1292.	0.4	72.0	71.1	0.9
31130.000	200.	1234.	0.4	72.0	71.1	0.9
32380.000	150.	627.	0.9	72.2	71.2	1.0
32406.000	25.	168.	3.2	72.1	71.0	1.1
32474.000	25.	175.	3.1	72.4	71.3	1.1
32497.000	40.	248.	2.2	72.5	71.6	0.9
33933.000	85.	598.	0.9	73.0	72.2	0.8
33960.000	18.	114.	4.7	72.8	71.8	1.0
33980.000	18.	115.	4.7	72.8	72.0	0.8
34000.000	55.	285.	1.9	73.1	72.6	0.5
36100.000	100.	503.	1.1	73.9	73.0	0.9
37400.000	200.	920.	0.6	74.0	73.1	0.9
38500.000	100.	469.	1.1	74.2	73.3	0.9
39475.000	100.	479.	1.1	74.4	73.5	0.9
46000.000	100.	467.	1.1	76.1	75.2	0.9

HEC 2 STATION 27289 = FIS STATION 26390 (W)

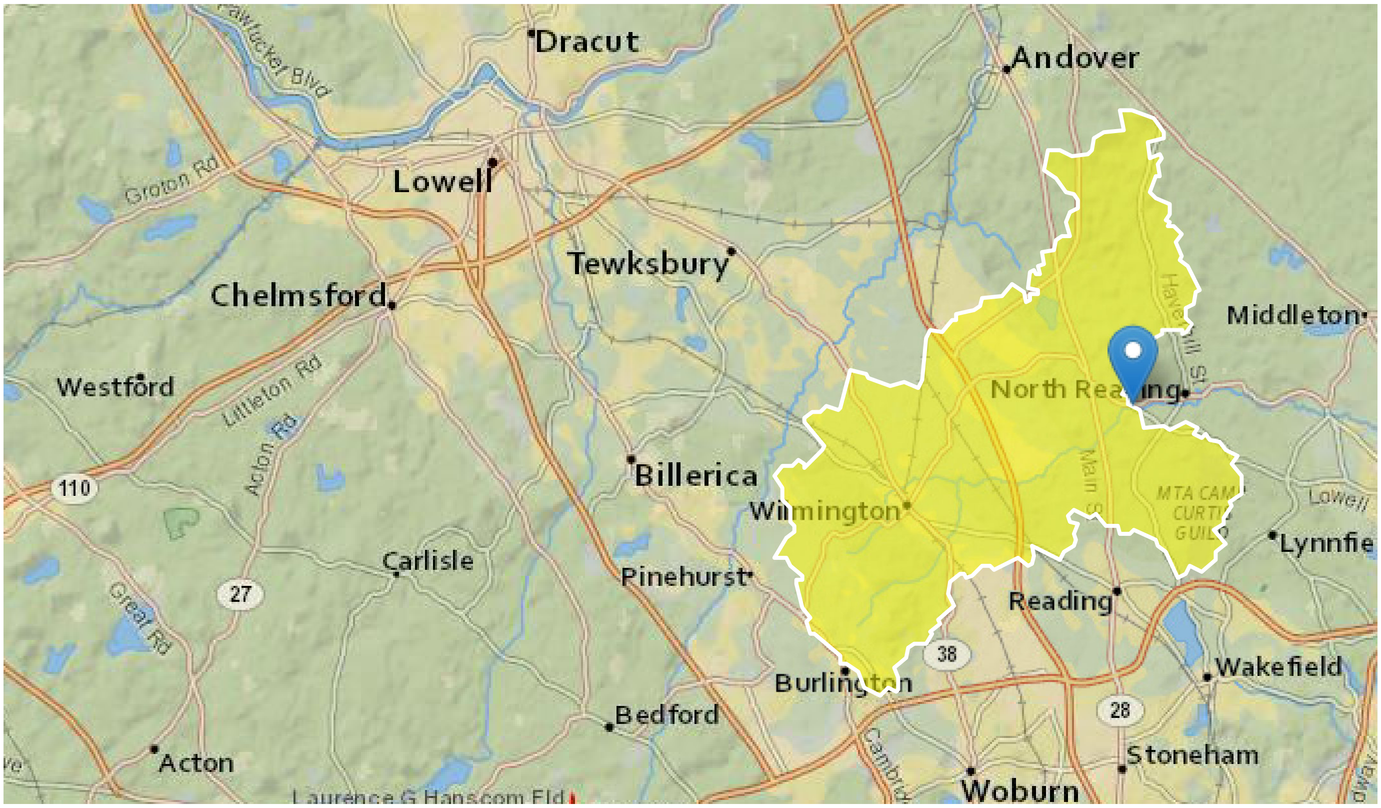
HEC 2 STATION 28189 = FIS STATION 27290 (X)

7.2 Hydrologic Analyses

7.2.1 Drainage Area Using USGS Streamstats
7.2.2 USGS Gauging Station Data for Gauge No. 01101500
7.2.3 PeakFQ Report
7.2.4 Hydrologic Calculations

StreamStats Report - Ipswich River @ Chestnut Street North Reading, MA

Region ID: MA
Workspace ID: MA20221026115125650000
Clicked Point (Latitude, Longitude): 42.57178, -71.09701
Time: 2022-10-26 07:51:46 -0400



Collapse All

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
ACRSDFT	Area underlain by stratified drift	23.5	square miles
BSLDEM10M	Mean basin slope computed from 10 m DEM	3.943	percent
BSLDEM250	Mean basin slope computed from 1:250K DEM	1.01	percent
CENTROIDX	Basin centroid horizontal (x) location in state plane coordinates	229697.6	meters

Parameter Code	Parameter Description	Value	Unit
CENTROIDY	Basin centroid vertical (y) location in state plane units	923954.9	meters
CRSDFT	Percentage of area of coarse-grained stratified drift	60.43	percent
CSL10_85	Change in elevation divided by length between points 10 and 85 percent of distance along main channel to basin divide - main channel method not known	8.13	feet per mi
DRNAREA	Area that drains to a point on a stream	37.1	square miles
ELEV	Mean Basin Elevation	110	feet
LC06STOR	Percentage of water bodies and wetlands determined from the NLCD 2006	18.65	percent

Peak-Flow Statistics

Peak-Flow Statistics Parameters [Peak Statewide 2016 5156]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	37.1	square miles	0.16	512
ELEV	Mean Basin Elevation	110	feet	80.6	1948
LC06STOR	Percent Storage from NLCD2006	18.65	percent	0	32.3

Peak-Flow Statistics Flow Report [Peak Statewide 2016 5156]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PIl	PIu	ASEp
50-percent AEP flood	496	ft^3/s	254	967	42.3
20-percent AEP flood	794	ft^3/s	402	1570	43.4
10-percent AEP flood	1020	ft^3/s	505	2060	44.7
4-percent AEP flood	1340	ft^3/s	641	2800	47.1

Statistic	Value	Unit	PIl	PIu	ASEp
2-percent AEP flood	1610	ft^3/s	747	3470	49.4
1-percent AEP flood	1880	ft^3/s	846	4180	51.8
0.5-percent AEP flood	2170	ft^3/s	948	4960	54.1
0.2-percent AEP flood	2590	ft^3/s	1080	6200	57.6

Peak-Flow Statistics Citations

Zarriello, P.J.,2017, Magnitude of flood flows at selected annual exceedance probabilities for streams in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2016–5156, 99 p. (https://dx.doi.org/10.3133/sir20165156)

Bankfull Statistics

Bankfull Statistics Parameters [Bankfull Statewide SIR2013 5155]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	37.1	square miles	0.6	329
BSLDEM10M	Mean Basin Slope from 10m DEM	3.943	percent	2.2	23.9

Bankfull Statistics Parameters [Appalachian Highlands D Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	37.1	square miles	0.07722	940.1535

Bankfull Statistics Parameters [New England P Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	37.1	square miles	3.799224	138.999861

Bankfull Statistics Parameters [USA Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	37.1	square miles	0.07722	59927.7393

Bankfull Statistics Flow Report [Bankfull Statewide SIR2013 5155]

PII: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	ASEp
Bankfull Width	56.2	ft	21.3
Bankfull Depth	2.48	ft	19.8
Bankfull Area	139	ft^2	29
Bankfull Streamflow	360	ft^3/s	55

Bankfull Statistics Flow Report [Appalachian Highlands D Bieger 2015]

Statistic	Value	Unit
Bieger_D_channel_width	68.1	ft
Bieger_D_channel_depth	3.16	ft
Bieger_D_channel_cross_sectional_area	219	ft^2

Bankfull Statistics Flow Report [New England P Bieger 2015]

Statistic	Value	Unit
Bieger_P_channel_width	69.5	ft
Bieger_P_channel_depth	3.05	ft
Bieger_P_channel_cross_sectional_area	219	ft^2

Bankfull Statistics Flow Report [USA Bieger 2015]

Statistic	Value	Unit
Bieger_USA_channel_width	44.2	ft
Bieger_USA_channel_depth	2.6	ft
Bieger_USA_channel_cross_sectional_area	120	ft^2

Bankfull Statistics Flow Report [Area-Averaged]

PII: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	ASEp
Bankfull Width	56.2	ft	21.3

Statistic	Value	Unit	ASEp
Bankfull Depth	2.48	ft	19.8
Bankfull Area	139	ft^2	29
Bankfull Streamflow	360	ft^3/s	55
Bieger_D_channel_width	68.1	ft	
Bieger_D_channel_depth	3.16	ft	
Bieger_D_channel_cross_sectional_area	219	ft^2	
Bieger_P_channel_width	69.5	ft	
Bieger_P_channel_depth	3.05	ft	
Bieger_P_channel_cross_sectional_area	219	ft^2	
Bieger_USA_channel_width	44.2	ft	
Bieger_USA_channel_depth	2.6	ft	
Bieger_USA_channel_cross_sectional_area	120	ft^2	

Bankfull Statistics Citations

Bent, G.C., and Waite, A.M.,2013, Equations for estimating bankfull channel geometry and discharge for streams in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2013–5155, 62 p., (http://pubs.usgs.gov/sir/2013/5155/)
Bieger, Katrin; Rathjens, Hendrik; Allen, Peter M.; and Arnold, Jeffrey G.,2015, Development and Evaluation of Bankfull Hydraulic Geometry Relationships for the Physiographic Regions of the United States, Publications from USDA-ARS / UNL Faculty, 17p. (https://digitalcommons.unl.edu/usdaarsfacpub/1515?utm_source=digitalcommons.unl.edu%2Fusdaarsfacpub%2F1515&utm_medium=PDF&utm_

USGS 01101500 IPSWICH RIVER AT SOUTH MIDDLETON, MA

Available data for this site Surface-water: Peak streamflow GO

Essex County, Massachusetts
Hydrologic Unit Code 01090001
Latitude 42°34'10", Longitude 71°01'39" NAD27
Drainage area 44.5 square miles
Contributing drainage area 44.5 square miles
Gage datum 44.16 feet above NAVD88

Output formats

Table
Graph
Tab-separated file
peakfq (watstore) format
Reselect output format

Water Year	Date	Gage Height (feet)	Stream-flow (cfs)
1938	1938-07-24	5.72	608[5]
1939	1939-04-03	4.42	400[5]
1940	1940-04-02	4.26	387[5]
1941	1941-03-30	2.45	194[5]
1942	1942-03-19	3.93	333[5]
1943	1943-05-23	3.48	280[5]

Water Year	Date	Gage Height (feet)	Stream-flow (cfs)
1944	1944-03-28	2.98	224[5]
1945	1945-03-07	4.04	347[5]
1946	1946-03-09	5.04	490[5]
1947	1947-03-06	3.63	297[5]
1948	1948-03-21	5.89	646[5]
1949	1949-02-25	2.36	171[5]
1950	1950-03-24	3.90	329[5]
1951	1951-02-19	3.85	324[5]
1952	1952-03-15	4.37	392[5]
1953	1953-03-31	4.61	426[5]
1954	1954-05-16	5.26	530[5]
1955	1954-12-19	4.41	302[5]
1956	1956-01-13	5.68	497[5]
1957	1957-04-10	3.61	232[5]
1958	1958-01-27	6.49	682[5]
1959	1959-03-07	4.71	354[5]
1960	1960-04-06	4.58	334[5]
1961	1961-04-17	4.66	368[5]
1962	1962-03-17	5.31	442[5]
1963	1962-10-07	6.99	808[5]
1964	1964-01-26	4.24	349[5]
1965	1965-02-26	3.28	204[5]
1966	1966-03-07	3.34[1]	197[5]
1967	1967-05-26	4.63	305[5]
1968	1968-03-19	7.09	833[5]
1969	1969-03-27	6.51	688[5]
1970	1969-12-27	5.90	550[5]
1971	1971-03-20	4.28	263[5]
1972	1972-03-23	5.53	476[5]
1973	1973-04-05	5.03	413[5]

Water Year	Date	Gage Height (feet)	Stream-flow (cfs)
1974	1973-12-21	4.36	292[5]
1975	1975-02-26	4.41	298[5]
1976	1976-02-02	4.98	380[5]
1977	1977-03-23		470[2,5]
1978	1978-03-28	5.35	445[5]
1979	1979-01-26	7.12	839[5]
1980	1980-04-11	3.19	177[5]
1981	1981-02-27	5.05	390[5]
1982	1982-06-07	6.55	697[5]
1983	1983-03-12	6.32	641[5]
1984	1984-06-03	6.54	694[5]
1985	1985-03-13	2.94	154[5]
1986	1986-03-15	5.39	487[5]
1987	1987-04-07	7.51	1,010[5]
1988	1988-03-28	3.93	246[5]
1989	1989-04-17	3.38	194[5]
1990	1990-04-04	4.42	321[5]
1991	1990-10-17	4.33	308[5]
1992	1992-06-06	3.19	176[5]
1993	1993-04-01	7.05	690[5]
1994	1994-03-25	5.81	547[5]
1995	1994-12-25	4.56	271[5]
1996	1996-01-28	5.77	436[5]
1997	1996-10-21	7.88	896[5]
1998	1998-06-15	6.69	604[5]
1999	1999-02-03	5.02	333[5]
2000	2000-04-23	5.63	415[5]
2001	2001-03-23	8.39	1,200[5]
2002	2002-05-19	4.02	214[5]
2003	2003-03-31	5.08	340[5]

Water Year	Date	Gage Height (feet)	Stream-flow (cfs)
2004	2004-04-02	7.06	783[5]
2005	2005-03-29	5.29	462[5]
2006	2006-05-15	8.46	1,330[5]
2007	2007-04-17	6.25	694[5]
2008	2008-03-09	5.53	544[5]
2009	2008-12-13	5.17	476[5]
2010	2010-03-15	8.43	1,320[5]
2011	2011-03-12	5.59	525[5]
2012	2011-12-09	4.63	320[5]
2013	2013-03-02	4.71	352[5]
2014	2014-03-31	5.82	546[5]
2015	2014-12-10	6.39	708[5]
2016	2016-04-08	3.65	217[5]
2017	2017-04-07	6.02	466[5]
2018	2018-04-17	5.48	437[5]
2019	2018-11-27	6.14	369[5]
2020	2019-12-14	5.39	295[5]
2021	2021-07-13	5.79	334[5]

?
Peak Gage-Height Qualification Codes.

- 1 -- Gage height affected by backwater

?
Peak Streamflow Qualification Codes.

- 2 -- Discharge is an Estimate
- 5 -- Discharge affected to unknown degree by Regulation or Diversion

---

1

```
Program PeakFq          U. S. GEOLOGICAL SURVEY           Seq.002.000
Version 7.4        Annual peak flow frequency analysis      Run Date / Time
5/ 4/2022                                        10/26/2022 12:46
```

--- PROCESSING OPTIONS ---

```
Plot option         = Graphics device
Basin char output   = None
Print option        = Yes
Debug print         = No
Input peaks listing = Long
Input peaks format  = WATSTORE peak file

Input files used:
  peaks (ascii)  - R:\22-0171 - Chestnut Street - North Reading\PEAK.TXT

  specifications - R:\22-0171 - Chestnut Street - North Reading\PKFQWPSF.TMP

Output file(s):
  main - R:\22-0171 - Chestnut Street - North Reading\PEAK.PRT
```

*** User responsible for assessment and interpretation of the following analysis ***

1

```
Program PeakFq          U. S. GEOLOGICAL SURVEY           Seq.001.001
Version 7.4        Annual peak flow frequency analysis      Run Date / Time
5/ 4/2022                                        10/26/2022 12:46
```

Station - 01101500 IPSWICH RIVER AT SOUTH MIDDLETON, MA

TABLE 1 - INPUT DATA SUMMARY

```
Number of peaks in record          =      84
Peaks not used in analysis         =       0
Gaged peaks in analysis            =      84
Historic peaks in analysis         =       0
Beginning Year                     =    1938
Ending Year                        =    2021
Historical Period Length           =      84
Skew option                        =   WEIGHTED
Regional skew                      =    0.700
   Standard error                  =    0.550
   Mean Square error               =    0.303
Gage base discharge                =      0.0
User supplied high outlier threshold =   --
User supplied PILF (LO) criterion    =   --
Plotting position parameter        =    0.00
Type of analysis                        EMA
```

PILF (LO) Test Method MGBT
Perceptible Ranges:

Start Year	End Year	Lower Bound	Upper Bound	
1938	2021	0.0	INF	DEFAULT

Interval Data = None Specified

TABLE 2 - DIAGNOSTIC MESSAGE AND PILF RESULTS

WCF002J-CALCS COMPLETED. RETURN CODE = 2
EMA002W-CONFIDENCE INTERVALS ARE NOT EXACT IF HISTORIC PERIOD > 0

MULTIPLE GRUBBS-BECK TEST RESULTS
MULTIPLE GRUBBS-BECK PILF THRESHOLD N/A
NUMBER OF PILFS IDENTIFIED 0

Kendall's Tau Parameters

	TAU	P-VALUE	MEDIAN SLOPE	No. of PEAKS
GAGED PEAKS	0.132	0.076	1.495	84

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.002
Version 7.4 Annual peak flow frequency analysis Run Date / Time
5/ 4/2022 10/26/2022 12:46

Station - 01101500 IPSWICH RIVER AT SOUTH MIDDLETON, MA

TABLE 3 - ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	LOGARITHMIC		
	MEAN	STANDARD DEVIATION	SKEW
EMA WITHOUT REG SKEW	2.6154	0.2098	0.232
EMA WITH REG SKEW	2.6154	0.2098	0.325

EMA ESTIMATE OF MSE OF SKEW WITHOUT REG SKEW 0.0751
EMA ESTIMATE OF MSE OF SKEW W/GAGED PEAKS ONLY (AT-SITE) 0.0751

TABLE 4 - ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	<- EMA ESTIMATE -> WITH REG SKEW	WITHOUT REG SKEW	<- FOR EMA ESTIMATE WITH REG SKEW -> LOG VARIANCE OF EST.	<-CONFIDENCE LIMITS-> 5.0% LOWER	95.0% UPPER
0.9950	137.7	132.0	0.0031	107.0	165.2
0.9900	150.6	145.6	0.0023	121.2	176.0
0.9500	195.3	192.6	0.0010	169.4	217.3
0.9000	226.4	225.0	0.0007	201.8	249.1
0.8000	273.1	273.4	0.0006	247.9	299.0
0.6667	328.2	330.1	0.0006	299.4	359.4
0.5000	401.8	404.8	0.0006	366.3	441.6
0.4292	438.2	441.5	0.0006	399.0	483.0
0.2000	613.6	615.5	0.0008	553.1	692.8
0.1000	777.2	774.4	0.0013	688.8	911.5
0.0400	1012.	997.5	0.0022	869.6	1272.0
0.0200	1208.	1180.	0.0033	1010.0	1616.0
0.0100	1422.	1377.	0.0047	1155.0	2035.0
0.0050	1658.	1590.	0.0065	1304.0	2546.0
0.0020	2006.	1899.	0.0093	1511.0	3396.0

*Note: If Station Skew option is selected then EMA ESTIMATE WITH REG SKEW will display values for and be equal to EMA ESTIMATE WITHOUT REG SKEW.

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.003
Version 7.4 Annual peak flow frequency analysis Run Date / Time
5/ 4/2022 10/26/2022 12:46

Station - 01101500 IPSWICH RIVER AT SOUTH MIDDLETON, MA

TABLE 5 - INPUT DATA LISTING

WATER YEAR	PEAK VALUE	PEAKFQ CODES	FLOW INTERVALS (WHERE LOWER BOUND NOT = UPPER BOUND) LOWER BOUND	UPPER BOUND	REMARKS
1938	608.0				
1939	400.0				
1940	387.0				
1941	194.0				
1942	333.0				
1943	280.0				
1944	224.0				
1945	347.0				
1946	490.0				
1947	297.0				
1948	646.0				
1949	171.0				
1950	329.0				

1951	324.0
1952	392.0
1953	426.0
1954	530.0
1955	302.0
1956	497.0
1957	232.0
1958	682.0
1959	354.0
1960	334.0
1961	368.0
1962	442.0
1963	808.0
1964	349.0
1965	204.0
1966	197.0
1967	305.0
1968	833.0
1969	688.0
1970	550.0
1971	263.0
1972	476.0
1973	413.0
1974	292.0
1975	298.0
1976	380.0
1977	470.0
1978	445.0
1979	839.0
1980	177.0
1981	390.0
1982	697.0
1983	641.0
1984	694.0
1985	154.0
1986	487.0
1987	1010.0
1988	246.0
1989	194.0
1990	321.0
1991	308.0
1992	176.0
1993	690.0
1994	547.0
1995	271.0
1996	436.0
1997	896.0
1998	604.0
1999	333.0
2000	415.0
2001	1200.0
2002	214.0
2003	340.0
2004	783.0

2005	462.0
2006	1330.0
2007	694.0
2008	544.0
2009	476.0
2010	1320.0
2011	525.0
2012	320.0
2013	352.0
2014	546.0
2015	708.0
2016	217.0
2017	466.0
2018	437.0
2019	369.0
2020	295.0
2021	334.0

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
O	O	Opportunistic peak
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.004
Version 7.4 Annual peak flow frequency analysis Run Date / Time
5/ 4/2022 10/26/2022 12:46

Station - 01101500 IPSWICH RIVER AT SOUTH MIDDLETON, MA

TABLE 6 - EMPIRICAL FREQUENCY CURVES -- HIRSCH-STEDINGER PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	EMA ESTIMATE	FLOW INTERVALS (WHERE LOWER BOUND NOT = UPPER BOUND) LOWER BOUND	UPPER BOUND
2006	1330.0	0.0117		

2010	1320.0	0.0235
2001	1200.0	0.0353
1987	1010.0	0.0470
1997	896.0	0.0588
1979	839.0	0.0706
1968	833.0	0.0823
1963	808.0	0.0941
2004	783.0	0.1059
2015	708.0	0.1176
1982	697.0	0.1294
1984	694.0	0.1529
2007	694.0	0.1412
1993	690.0	0.1647
1969	688.0	0.1764
1958	682.0	0.1882
1948	646.0	0.2000
1983	641.0	0.2117
1938	608.0	0.2235
1998	604.0	0.2353
1970	550.0	0.2470
1994	547.0	0.2588
2014	546.0	0.2706
2008	544.0	0.2823
1954	530.0	0.2941
2011	525.0	0.3059
1956	497.0	0.3176
1946	490.0	0.3294
1986	487.0	0.3412
1972	476.0	0.3647
2009	476.0	0.3529
1977	470.0	0.3765
2017	466.0	0.3882
2005	462.0	0.4000
1978	445.0	0.4118
1962	442.0	0.4235
2018	437.0	0.4353
1996	436.0	0.4471
1953	426.0	0.4588
2000	415.0	0.4706
1973	413.0	0.4824
1939	400.0	0.4941
1952	392.0	0.5059
1981	390.0	0.5176
1940	387.0	0.5294
1976	380.0	0.5412
2019	369.0	0.5529
1961	368.0	0.5647
1959	354.0	0.5765
2013	352.0	0.5882
1964	349.0	0.6000
1945	347.0	0.6118
2003	340.0	0.6235
1960	334.0	0.6471
2021	334.0	0.6353

1942	333.0	0.6706
1999	333.0	0.6588
1950	329.0	0.6824
1951	324.0	0.6941
1990	321.0	0.7059
2012	320.0	0.7177
1991	308.0	0.7294
1967	305.0	0.7412
1955	302.0	0.7530
1975	298.0	0.7647
1947	297.0	0.7765
2020	295.0	0.7883
1974	292.0	0.8000
1943	280.0	0.8118
1995	271.0	0.8236
1971	263.0	0.8353
1988	246.0	0.8471
1957	232.0	0.8588
1944	224.0	0.8706
2016	217.0	0.8824
2002	214.0	0.8941
1965	204.0	0.9059
1966	197.0	0.9177
1941	194.0	0.9412
1989	194.0	0.9294
1980	177.0	0.9530
1992	176.0	0.9647
1949	171.0	0.9765
1985	154.0	0.9883

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.005
Version 7.4 Annual peak flow frequency analysis Run Date / Time
5/ 4/2022 10/26/2022 12:46

Station - 01101500 IPSWICH RIVER AT SOUTH MIDDLETON, MA

TABLE 7 - EMA REPRESENTATION OF DATA

WATER	<----- OBSERVED ---->		<-------- EMA ------->		<---- USER-ENTERED ----><- PERCEPTIBLE RANGES ->		<-------- FINAL -------><- PERCEPTIBLE RANGES ->	
YEAR	Q_LOWER	Q_UPPER	Q_LOWER	Q_UPPER	LOWER	UPPER	LOWER	UPPER
1938	608.0	608.0	608.0	608.0	0.0	INF	0.0	INF
1939	400.0	400.0	400.0	400.0	0.0	INF	0.0	INF
1940	387.0	387.0	387.0	387.0	0.0	INF	0.0	INF
1941	194.0	194.0	194.0	194.0	0.0	INF	0.0	INF
1942	333.0	333.0	333.0	333.0	0.0	INF	0.0	INF
1943	280.0	280.0	280.0	280.0	0.0	INF	0.0	INF
1944	224.0	224.0	224.0	224.0	0.0	INF	0.0	INF
1945	347.0	347.0	347.0	347.0	0.0	INF	0.0	INF

1946	490.0	490.0	490.0	490.0	0.0	INF	0.0	INF
1947	297.0	297.0	297.0	297.0	0.0	INF	0.0	INF
1948	646.0	646.0	646.0	646.0	0.0	INF	0.0	INF
1949	171.0	171.0	171.0	171.0	0.0	INF	0.0	INF
1950	329.0	329.0	329.0	329.0	0.0	INF	0.0	INF
1951	324.0	324.0	324.0	324.0	0.0	INF	0.0	INF
1952	392.0	392.0	392.0	392.0	0.0	INF	0.0	INF
1953	426.0	426.0	426.0	426.0	0.0	INF	0.0	INF
1954	530.0	530.0	530.0	530.0	0.0	INF	0.0	INF
1955	302.0	302.0	302.0	302.0	0.0	INF	0.0	INF
1956	497.0	497.0	497.0	497.0	0.0	INF	0.0	INF
1957	232.0	232.0	232.0	232.0	0.0	INF	0.0	INF
1958	682.0	682.0	682.0	682.0	0.0	INF	0.0	INF
1959	354.0	354.0	354.0	354.0	0.0	INF	0.0	INF
1960	334.0	334.0	334.0	334.0	0.0	INF	0.0	INF
1961	368.0	368.0	368.0	368.0	0.0	INF	0.0	INF
1962	442.0	442.0	442.0	442.0	0.0	INF	0.0	INF
1963	808.0	808.0	808.0	808.0	0.0	INF	0.0	INF
1964	349.0	349.0	349.0	349.0	0.0	INF	0.0	INF
1965	204.0	204.0	204.0	204.0	0.0	INF	0.0	INF
1966	197.0	197.0	197.0	197.0	0.0	INF	0.0	INF
1967	305.0	305.0	305.0	305.0	0.0	INF	0.0	INF
1968	833.0	833.0	833.0	833.0	0.0	INF	0.0	INF
1969	688.0	688.0	688.0	688.0	0.0	INF	0.0	INF
1970	550.0	550.0	550.0	550.0	0.0	INF	0.0	INF
1971	263.0	263.0	263.0	263.0	0.0	INF	0.0	INF
1972	476.0	476.0	476.0	476.0	0.0	INF	0.0	INF
1973	413.0	413.0	413.0	413.0	0.0	INF	0.0	INF
1974	292.0	292.0	292.0	292.0	0.0	INF	0.0	INF
1975	298.0	298.0	298.0	298.0	0.0	INF	0.0	INF
1976	380.0	380.0	380.0	380.0	0.0	INF	0.0	INF
1977	470.0	470.0	470.0	470.0	0.0	INF	0.0	INF
1978	445.0	445.0	445.0	445.0	0.0	INF	0.0	INF
1979	839.0	839.0	839.0	839.0	0.0	INF	0.0	INF
1980	177.0	177.0	177.0	177.0	0.0	INF	0.0	INF
1981	390.0	390.0	390.0	390.0	0.0	INF	0.0	INF
1982	697.0	697.0	697.0	697.0	0.0	INF	0.0	INF
1983	641.0	641.0	641.0	641.0	0.0	INF	0.0	INF
1984	694.0	694.0	694.0	694.0	0.0	INF	0.0	INF
1985	154.0	154.0	154.0	154.0	0.0	INF	0.0	INF
1986	487.0	487.0	487.0	487.0	0.0	INF	0.0	INF
1987	1010.0	1010.0	1010.0	1010.0	0.0	INF	0.0	INF
1988	246.0	246.0	246.0	246.0	0.0	INF	0.0	INF
1989	194.0	194.0	194.0	194.0	0.0	INF	0.0	INF
1990	321.0	321.0	321.0	321.0	0.0	INF	0.0	INF
1991	308.0	308.0	308.0	308.0	0.0	INF	0.0	INF
1992	176.0	176.0	176.0	176.0	0.0	INF	0.0	INF
1993	690.0	690.0	690.0	690.0	0.0	INF	0.0	INF
1994	547.0	547.0	547.0	547.0	0.0	INF	0.0	INF
1995	271.0	271.0	271.0	271.0	0.0	INF	0.0	INF
1996	436.0	436.0	436.0	436.0	0.0	INF	0.0	INF
1997	896.0	896.0	896.0	896.0	0.0	INF	0.0	INF
1998	604.0	604.0	604.0	604.0	0.0	INF	0.0	INF
1999	333.0	333.0	333.0	333.0	0.0	INF	0.0	INF

2000	415.0	415.0	415.0	415.0	0.0	INF	0.0	INF
2001	1200.0	1200.0	1200.0	1200.0	0.0	INF	0.0	INF
2002	214.0	214.0	214.0	214.0	0.0	INF	0.0	INF
2003	340.0	340.0	340.0	340.0	0.0	INF	0.0	INF
2004	783.0	783.0	783.0	783.0	0.0	INF	0.0	INF
2005	462.0	462.0	462.0	462.0	0.0	INF	0.0	INF
2006	1330.0	1330.0	1330.0	1330.0	0.0	INF	0.0	INF
2007	694.0	694.0	694.0	694.0	0.0	INF	0.0	INF
2008	544.0	544.0	544.0	544.0	0.0	INF	0.0	INF
2009	476.0	476.0	476.0	476.0	0.0	INF	0.0	INF
2010	1320.0	1320.0	1320.0	1320.0	0.0	INF	0.0	INF
2011	525.0	525.0	525.0	525.0	0.0	INF	0.0	INF
2012	320.0	320.0	320.0	320.0	0.0	INF	0.0	INF
2013	352.0	352.0	352.0	352.0	0.0	INF	0.0	INF
2014	546.0	546.0	546.0	546.0	0.0	INF	0.0	INF
2015	708.0	708.0	708.0	708.0	0.0	INF	0.0	INF
2016	217.0	217.0	217.0	217.0	0.0	INF	0.0	INF
2017	466.0	466.0	466.0	466.0	0.0	INF	0.0	INF
2018	437.0	437.0	437.0	437.0	0.0	INF	0.0	INF
2019	369.0	369.0	369.0	369.0	0.0	INF	0.0	INF
2020	295.0	295.0	295.0	295.0	0.0	INF	0.0	INF
2021	334.0	334.0	334.0	334.0	0.0	INF	0.0	INF

1

End PeakFQ analysis.
Stations processed : 1
Number of errors : 0
Stations skipped : 0
Station years : 84

Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4, or *.)
(2, 4, and * records are ignored.)

For the station below, the following records were ignored:

FINISHED PROCESSING STATION: 01101500 USGS IPSWICH RIVER AT SOUTH MIDDLE

For the station below, the following records were ignored:

FINISHED PROCESSING STATION:

Drainage Area Ratio (Qu/Qg)

Project Name:	Ipswich River @ Chestnut Street, North Reading
Project Location:	Chestnut Street, North Reading
Project Job Number:	22-0171

USGS Gauging Station: 1101500

Description: Approximate 3.9 miles downstream of the site

Q_g - Area of gauged site (mi^2): 43.4

Q_u - Area of ungauged site (mi^2): 37.1

Drainage Area Ratio (Q_u/Q_g): 0.855

Regional exponent (b) for drainage area adjustment of flood flows at an ungaged site on a gaged stream in Massachusetts.

(Table 12, USGS Scientific Investigations Report 2016-5156)	50 (2-yr)	20 (5-yr)	10 (10-yr)	4 (25-yr)	2 (50-yr)	1 (100-yr)	0.5 (200-yr)	0.2 (500-yr)
	0.8	0.79	0.78	0.78	0.77	0.77	0.76	0.76

Adjusted Flow for Site = $(Q_u/Q_g)^b \times Q_g$

Annual Probability Flood Event	**Peak Flow @ USGS Gauge 01101500**	**Peak Flow @ Site (cfs)**
10% (10-year)	777	688
4% (25-year)	1,012	895
2% (50-year)	1,208	1,071
1% (100-year)	1,422	1,260
0.2% (500-year)	1,658	1,472

7.3 Hydraulic Analyses

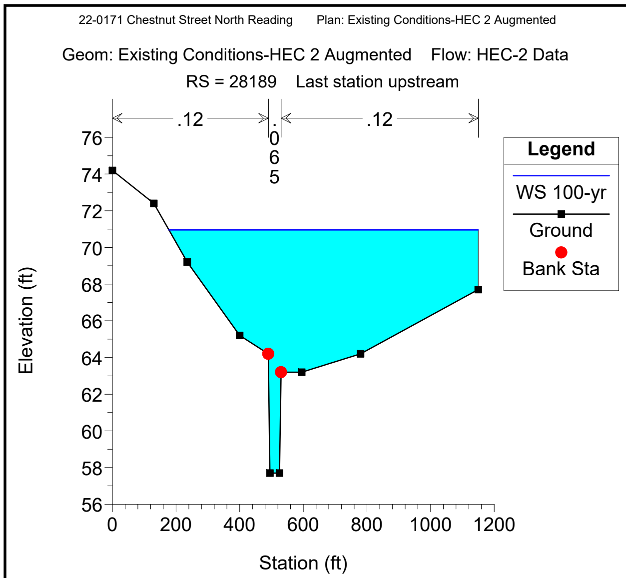
7.3.1 Existing Conditions – FIS Flow

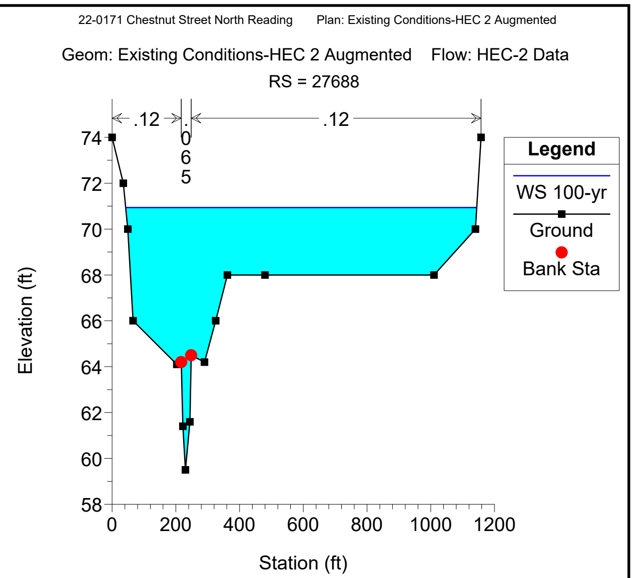
7.3.1 - Existing Conditions - FIS Flow

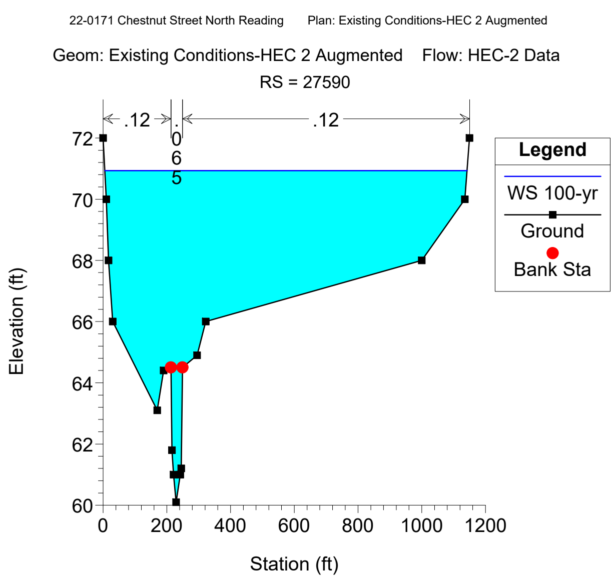
Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
N.Reading	28189	100-yr	1035	57.7	70.96		70.96	0.000018	0.48	5431.7	972.6	0.02
N.Reading	27688	100-yr	1035	59.5	70.94		70.94	0.000055	0.74	4041.72	1101.8	0.04
N.Reading	27590	100-yr	1035	60.1	70.94		70.94	0.00003	0.55	4972.78	1136.7	0.03
N.Reading	27430	100-yr	1035	58	70.93		70.93	0.000035	0.62	4774.16	1212.77	0.03
N.Reading	27303	100-yr	1035	62	70.92		70.93	0.000077	0.83	3822.24	1487.17	0.05
N.Reading	27289	100-yr	1035	57.2	70.92	65.78	70.92	0.000123	0.86	4225.2	1869.11	0.06
N.Reading	27263		Culvert									
N.Reading	27223	100-yr	1035	62.1	70.42	70.42	70.92	0.00204	10.97	1420.34	1379.03	0.67
N.Reading	27173	100-yr	1035	58.7	68.39		68.45	0.001136	2.39	1195.09	884.07	0.17
N.Reading	26942	100-yr	1035	59.6	67.85		68.03	0.002535	3.67	398.24	138.66	0.26
N.Reading	26796	100-yr	1035	58.1	67.74	63.74	67.79	0.000891	2.26	1293.68	740.43	0.15
N.Reading	25420	100-yr	1035	59.4	66.14	62.93	66.22	0.001502	2.72	766.01	355.73	0.2

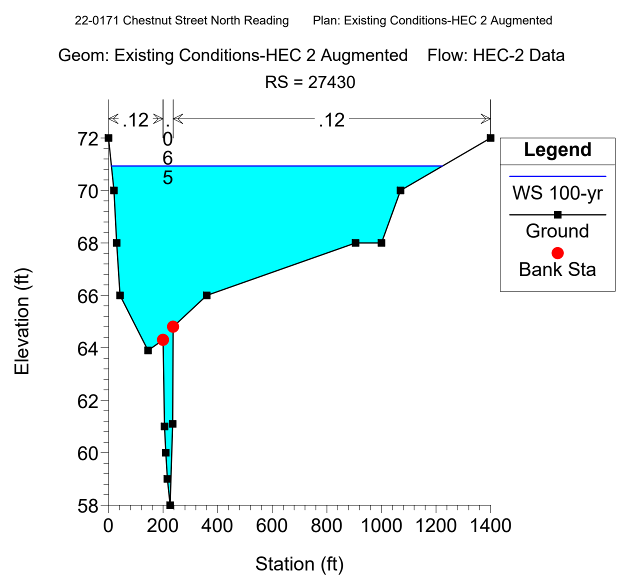
Plan: Existing Conditions-HEC 2 Augmented   Ipswich River   N.Reading RS: 27263.0   Culv Group: Twim CMPs   Profile: 100-yr

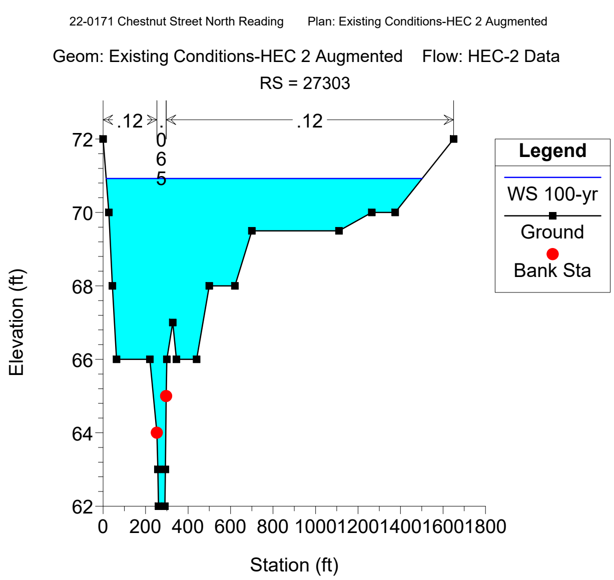
Q Culv Group (cfs)	92.20	Culv Full Len (ft)	41.00
# Barrels	2	Culv Vel US (ft/s)	0.46
Q Barrel (cfs)	46.10	Culv Vel DS (ft/s)	0.46
E.G. US. (ft)	70.92	Culv Inv El Up (ft)	60.80
W.S. US. (ft)	70.92	Culv Inv El Dn (ft)	60.60
E.G. DS (ft)	70.92	Culv Frctn Ls (ft)	0.00
W.S. DS (ft)	70.42	Culv Exit Loss (ft)	0.00
Delta EG (ft)	0.00	Culv Entr Loss (ft)	0.00
Delta WS (ft)	0.50	Q Weir (cfs)	942.80
E.G. IC (ft)	66.71	Weir Sta Lft (ft)	1102.35
E.G. OC (ft)	70.92	Weir Sta Rgt (ft)	2269.02
Culvert Control	Outlet	Weir Submerg	1.00
Culv WS Inlet (ft)	70.10	Weir Max Depth (ft)	2.22
Culv WS Outlet (ft)	69.90	Weir Avg Depth (ft)	1.67
Culv Nml Depth (ft)		Weir Flow Area (sq ft)	1952.89
Culv Crt Depth (ft)	0.71	Min El Weir Flow (ft)	68.91

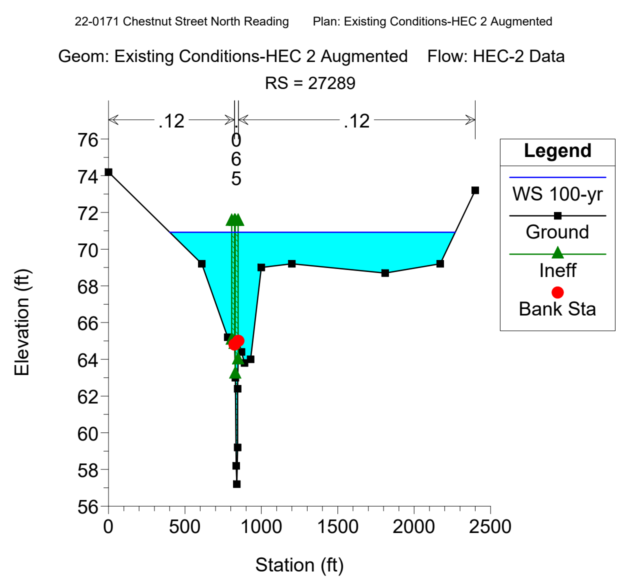

22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 28189 Last station upstream
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

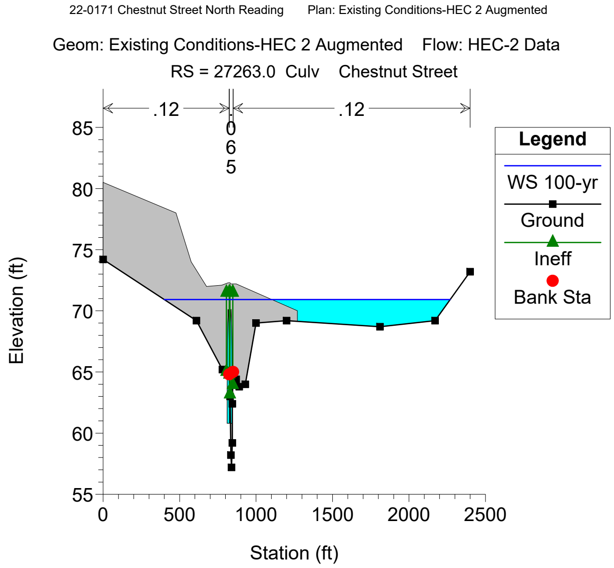

22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 27688
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

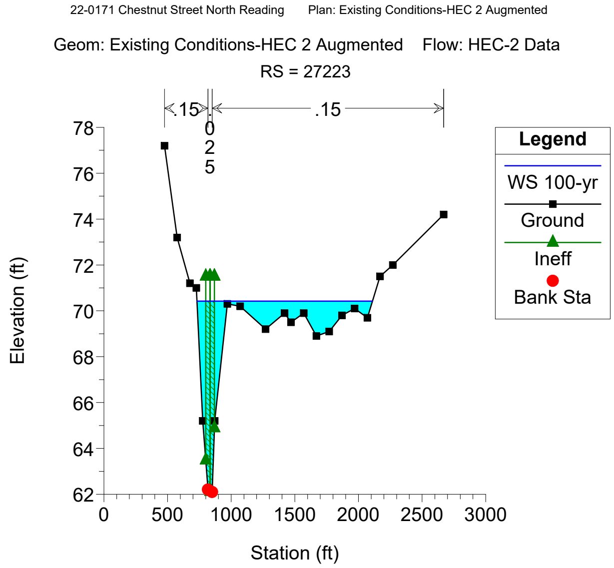

22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 27590
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

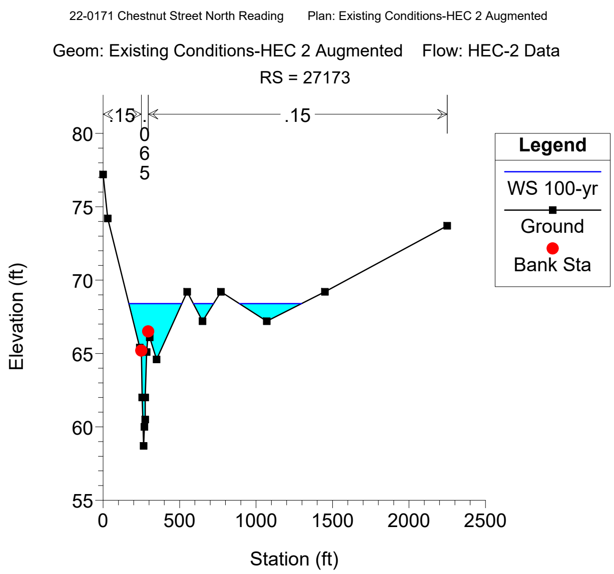

22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 27430
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

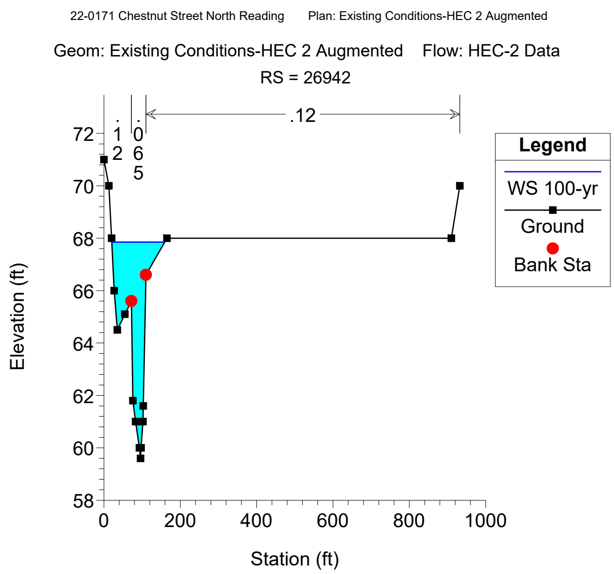

22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 27303
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

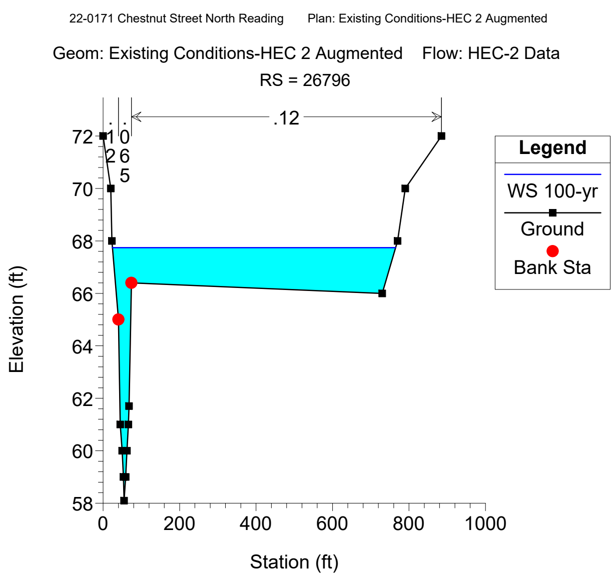

22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 27289
.12
.065
.12
Legend
WS 100-yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

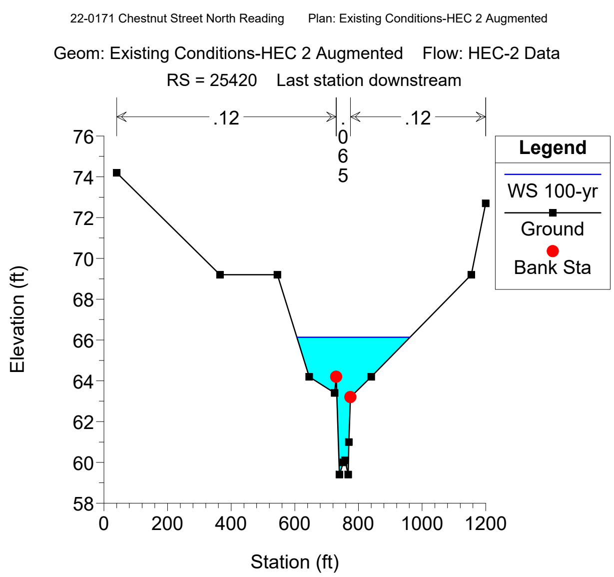

22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 27263.0 Culv Chestnut Street
.12
.065
.12
Legend
WS 100-yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 27223
.15
.025
.15
Legend
WS 100-yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 27173
.15
.065
.15
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 26942
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 26796
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Existing Conditions-HEC 2 Augmented
Geom: Existing Conditions-HEC 2 Augmented Flow: HEC-2 Data
RS = 25420 Last station downstream
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

7.3.2 Existing Conditions – USGS PeakFQ Flows

7.3.2 - Existing Conditions - USGS PeakFQ Flows

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
N.Reading	28189	10 yr	688	57.7	70.35		70.36	0.000011	0.36	4853.51	952.89	0.02
N.Reading	28189	25 yr	895	57.7	70.71		70.71	0.000015	0.43	5191.99	964.48	0.02
N.Reading	28189	50 yr	1071	57.7	70.98		70.98	0.000019	0.49	5458.15	973.49	0.02
N.Reading	28189	100 yr	1260	57.7	71.12		71.12	0.000024	0.56	5590.49	977.94	0.03
N.Reading	27688	10 yr	688	59.5	70.34		70.35	0.000039	0.6	3388.2	1094.96	0.04
N.Reading	27688	25 yr	895	59.5	70.69		70.7	0.00005	0.69	3771.59	1098.97	0.04
N.Reading	27688	50 yr	1071	59.5	70.97		70.97	0.000057	0.76	4070.73	1102.1	0.04
N.Reading	27688	100 yr	1260	59.5	71.1		71.1	0.000072	0.85	4215.09	1103.61	0.05
N.Reading	27590	10 yr	688	60.1	70.34		70.34	0.000021	0.44	4299.84	1129.27	0.03
N.Reading	27590	25 yr	895	60.1	70.69		70.69	0.000027	0.51	4694.52	1133.63	0.03
N.Reading	27590	50 yr	1071	60.1	70.96		70.96	0.000032	0.57	5002.52	1137.02	0.03
N.Reading	27590	100 yr	1260	60.1	71.09		71.09	0.000041	0.64	5150.44	1138.65	0.04
N.Reading	27430	10 yr	688	58	70.34		70.34	0.000022	0.48	4086.9	1109.18	0.03
N.Reading	27430	25 yr	895	58	70.69		70.69	0.00003	0.57	4482.98	1170	0.03
N.Reading	27430	50 yr	1071	58	70.96		70.96	0.000037	0.64	4805.57	1217.29	0.03
N.Reading	27430	100 yr	1260	58	71.08		71.09	0.000047	0.73	4963.25	1239.76	0.04
N.Reading	27303	10 yr	688	62	70.33		70.33	0.000061	0.7	2971.15	1398.08	0.04
N.Reading	27303	25 yr	895	62	70.68		70.68	0.000073	0.79	3464.13	1450.35	0.05
N.Reading	27303	50 yr	1071	62	70.95		70.95	0.000081	0.85	3860.14	1491.01	0.05
N.Reading	27303	100 yr	1260	62	71.07		71.08	0.0001	0.95	4049.53	1510.07	0.06
N.Reading	27289	10 yr	688	57.2	70.33	65.43	70.33	0.000126	0.82	3175.16	1763.17	0.06
N.Reading	27289	25 yr	895	57.2	70.68	65.64	70.68	0.000127	0.86	3783.68	1825.32	0.06
N.Reading	27289	50 yr	1071	57.2	70.95	65.82	70.95	0.000127	0.88	4271.93	1873.68	0.06
N.Reading	27289	100 yr	1260	57.2	71.07	65.98	71.08	0.00015	0.97	4505.42	1896.36	0.06
N.Reading	27263		Culvert									
N.Reading	27223	10 yr	688	62.1	69.43	69.43	70.33	0.00298	12.18	480.67	508.29	0.8
N.Reading	27223	25 yr	895	62.1	70.09	70.09	70.67	0.002225	11.16	1011.08	1228.69	0.7
N.Reading	27223	50 yr	1071	62.1	70.45	70.45	70.94	0.00206	11.05	1459.8	1380.95	0.68
N.Reading	27223	100 yr	1260	62.1	70.63	70.63	71.07	0.002036	11.15	1696.93	1392.47	0.68
N.Reading	27173	10 yr	688	58.7	67.63		67.69	0.001128	2.17	672.6	490.88	0.17
N.Reading	27173	25 yr	895	58.7	68.1		68.16	0.001169	2.34	958.08	732.36	0.17
N.Reading	27173	50 yr	1071	58.7	68.44		68.5	0.001153	2.42	1238.74	909.25	0.17
N.Reading	27173	100 yr	1260	58.7	68.77		68.82	0.001114	2.46	1560.99	1077.11	0.17
N.Reading	26942	10 yr	688	59.6	67.25		67.36	0.001716	2.82	322.16	112.77	0.21
N.Reading	26942	25 yr	895	59.6	67.61		67.77	0.002237	3.36	366.26	128.42	0.24
N.Reading	26942	50 yr	1071	59.6	67.88		68.07	0.002671	3.78	401.53	139.67	0.27
N.Reading	26942	100 yr	1260	59.6	68.13	64.69	68.35	0.003101	4.18	531.91	891.83	0.29
N.Reading	26796	10 yr	688	58.1	67.1		67.15	0.001006	2.25	820.84	723.86	0.16
N.Reading	26796	25 yr	895	58.1	67.48		67.53	0.000955	2.28	1101.43	733.74	0.16
N.Reading	26796	50 yr	1071	58.1	67.76		67.81	0.000929	2.31	1308.6	740.95	0.16
N.Reading	26796	100 yr	1260	58.1	68.03	64.28	68.08	0.000912	2.35	1509.45	747.39	0.16
N.Reading	25420	10 yr	688	59.4	64.18	62.22	64.41	0.005608	3.95	229.02	191.66	0.36
N.Reading	25420	25 yr	895	59.4	64.62	62.66	64.88	0.005605	4.26	323.08	230.26	0.37
N.Reading	25420	50 yr	1071	59.4	64.94	63	65.2	0.005603	4.47	398.99	256.17	0.37
N.Reading	25420	100 yr	1260	59.4	65.23	63.37	65.5	0.005602	4.67	477.68	280.5	0.38

Plan: Existing Conditions-USGS Flow   Ipswich River   N.Reading RS: 27263.0   Culv Group: Twim CMPs   Profile: 10 yr

Q Culv Group (cfs)	75.90	Culv Full Len (ft)	41.00
# Barrels	2	Culv Vel US (ft/s)	0.38
Q Barrel (cfs)	37.95	Culv Vel DS (ft/s)	0.38
E.G. US. (ft)	70.33	Culv Inv El Up (ft)	60.80
W.S. US. (ft)	70.33	Culv Inv El Dn (ft)	60.60
E.G. DS (ft)	70.33	Culv Frctn Ls (ft)	0.00
W.S. DS (ft)	69.43	Culv Exit Loss (ft)	0.00
Delta EG (ft)	0.00	Culv Entr Loss (ft)	0.00
Delta WS (ft)	0.90	Q Weir (cfs)	612.10
E.G. IC (ft)	65.23	Weir Sta Lft (ft)	1209.54
E.G. OC (ft)	70.33	Weir Sta Rgt (ft)	2235.12
Culvert Control	Outlet	Weir Submerg	0.98
Culv WS Inlet (ft)	70.10	Weir Max Depth (ft)	1.63
Culv WS Outlet (ft)	70.33	Weir Avg Depth (ft)	1.27
Culv Nml Depth (ft)		Weir Flow Area (sq ft)	1306.68
Culv Crt Depth (ft)	0.62	Min El Weir Flow (ft)	68.91

Plan: Existing Conditions-USGS Flow   Ipswich River   N.Reading RS: 27263.0   Culv Group: Twim CMPs   Profile: 25 yr

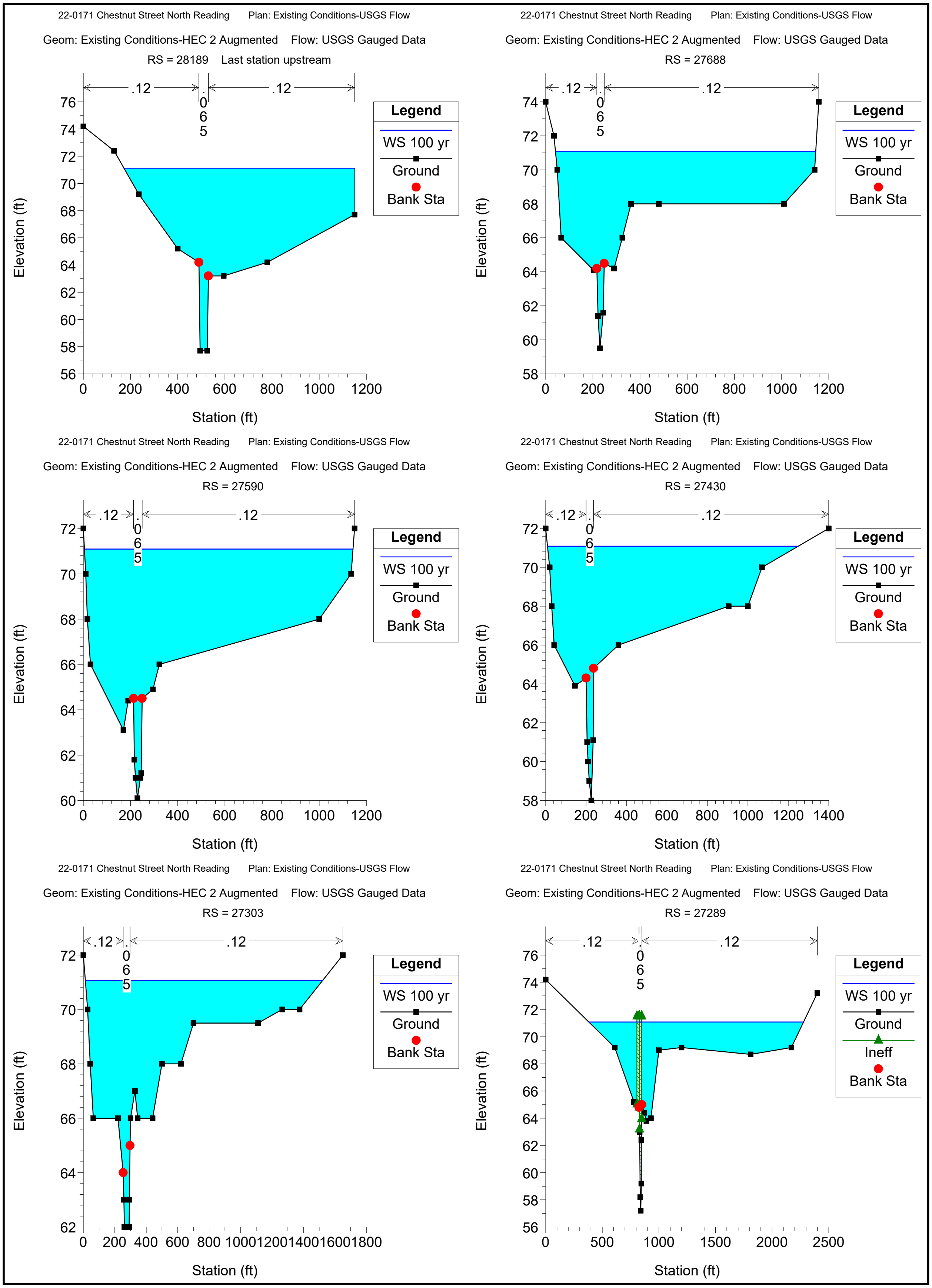
Q Culv Group (cfs)	92.21	Culv Full Len (ft)	41.00
# Barrels	2	Culv Vel US (ft/s)	0.46
Q Barrel (cfs)	46.10	Culv Vel DS (ft/s)	0.46
E.G. US. (ft)	70.68	Culv Inv El Up (ft)	60.80
W.S. US. (ft)	70.68	Culv Inv El Dn (ft)	60.60
E.G. DS (ft)	70.67	Culv Frctn Ls (ft)	0.00
W.S. DS (ft)	70.09	Culv Exit Loss (ft)	0.00
Delta EG (ft)	0.00	Culv Entr Loss (ft)	0.00
Delta WS (ft)	0.58	Q Weir (cfs)	802.79
E.G. IC (ft)	66.13	Weir Sta Lft (ft)	1146.75
E.G. OC (ft)	70.68	Weir Sta Rgt (ft)	2254.98
Culvert Control	Outlet	Weir Submerg	0.99
Culv WS Inlet (ft)	70.10	Weir Max Depth (ft)	1.98
Culv WS Outlet (ft)	69.90	Weir Avg Depth (ft)	1.51
Culv Nml Depth (ft)		Weir Flow Area (sq ft)	1675.17
Culv Crt Depth (ft)	0.71	Min El Weir Flow (ft)	68.91

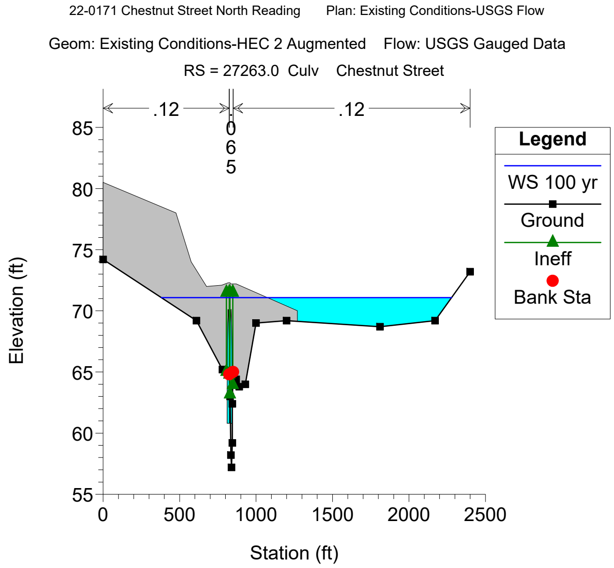
Plan: Existing Conditions-USGS Flow   Ipswich River   N.Reading RS: 27263.0   Culv Group: Twim CMPs   Profile: 50 yr

Q Culv Group (cfs)	87.34	Culv Full Len (ft)	41.00
# Barrels	2	Culv Vel US (ft/s)	0.44
Q Barrel (cfs)	43.67	Culv Vel DS (ft/s)	0.44
E.G. US. (ft)	70.95	Culv Inv El Up (ft)	60.80
W.S. US. (ft)	70.95	Culv Inv El Dn (ft)	60.60
E.G. DS (ft)	70.94	Culv Frctn Ls (ft)	0.00
W.S. DS (ft)	70.45	Culv Exit Loss (ft)	0.00
Delta EG (ft)	0.00	Culv Entr Loss (ft)	0.00
Delta WS (ft)	0.50	Q Weir (cfs)	983.66
E.G. IC (ft)	66.85	Weir Sta Lft (ft)	1097.61
E.G. OC (ft)	70.95	Weir Sta Rgt (ft)	2270.52
Culvert Control	Outlet	Weir Submerg	1.00
Culv WS Inlet (ft)	70.10	Weir Max Depth (ft)	2.25
Culv WS Outlet (ft)	69.90	Weir Avg Depth (ft)	1.69
Culv Nml Depth (ft)		Weir Flow Area (sq ft)	1983.41
Culv Crt Depth (ft)	0.68	Min El Weir Flow (ft)	68.91

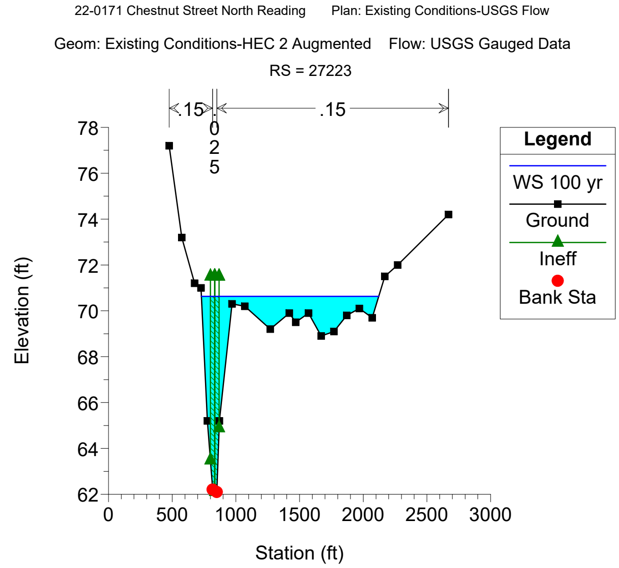
Plan: Existing Conditions-USGS Flow   Ipswich River   N.Reading RS: 27263.0   Culv Group: Twim CMPs   Profile: 100 yr

Q Culv Group (cfs)	92.02	Culv Full Len (ft)	41.00
# Barrels	2	Culv Vel US (ft/s)	0.46
Q Barrel (cfs)	46.01	Culv Vel DS (ft/s)	0.46
E.G. US. (ft)	71.08	Culv Inv El Up (ft)	60.80
W.S. US. (ft)	71.07	Culv Inv El Dn (ft)	60.60
E.G. DS (ft)	71.07	Culv Frctn Ls (ft)	0.00
W.S. DS (ft)	70.63	Culv Exit Loss (ft)	0.00
Delta EG (ft)	0.00	Culv Entr Loss (ft)	0.00
Delta WS (ft)	0.44	Q Weir (cfs)	1167.98
E.G. IC (ft)	67.60	Weir Sta Lft (ft)	1074.58
E.G. OC (ft)	71.08	Weir Sta Rgt (ft)	2277.80
Culvert Control	Outlet	Weir Submerg	1.00
Culv WS Inlet (ft)	70.10	Weir Max Depth (ft)	2.37
Culv WS Outlet (ft)	69.90	Weir Avg Depth (ft)	1.77
Culv Nml Depth (ft)		Weir Flow Area (sq ft)	2133.89
Culv Crt Depth (ft)	0.71	Min El Weir Flow (ft)	68.91

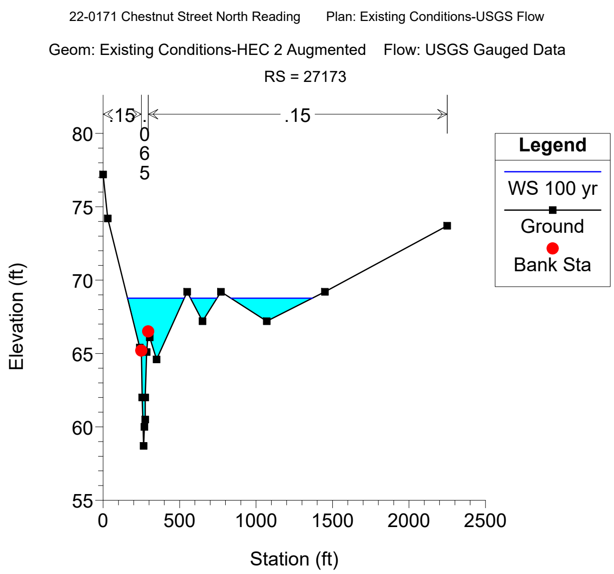

22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 28189 Last station upstream
.12
.065
.12
Elevation (ft)
Station (ft)
Legend
WS 100 yr
Ground
Bank Sta
22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 27688
Legend
WS 100 yr
Ground
Bank Sta
22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 27590
Legend
WS 100 yr
Ground
Bank Sta
22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 27430
Legend
WS 100 yr
Ground
Bank Sta
22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 27303
Legend
WS 100 yr
Ground
Bank Sta
22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 27289
Legend
WS 100 yr
Ground
Ineff
Bank Sta



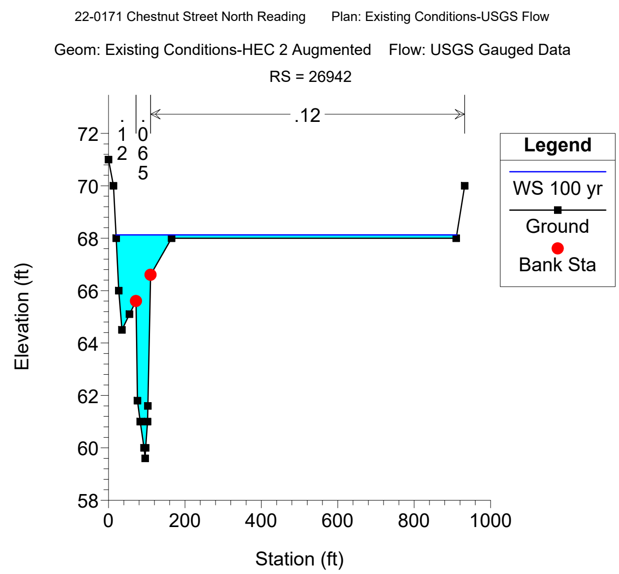
22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 27263.0 Culv Chestnut Street
.12
0
6
5
.12
85
80
75
70
65
60
55
0
500
1000
1500
2000
2500
Elevation (ft)
Station (ft)
Legend
WS 100 yr
Ground
Ineff
Bank Sta



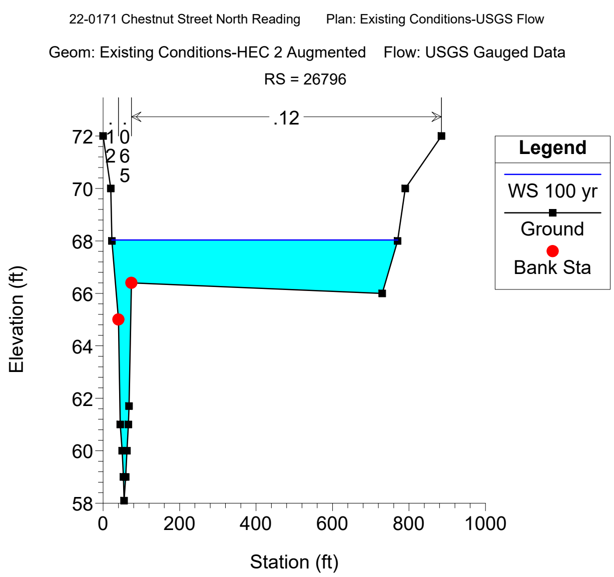
22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 27223
.15
0
2
5
.15
78
76
74
72
70
68
66
64
62
0
500
1000
1500
2000
2500
3000
Elevation (ft)
Station (ft)
Legend
WS 100 yr
Ground
Ineff
Bank Sta



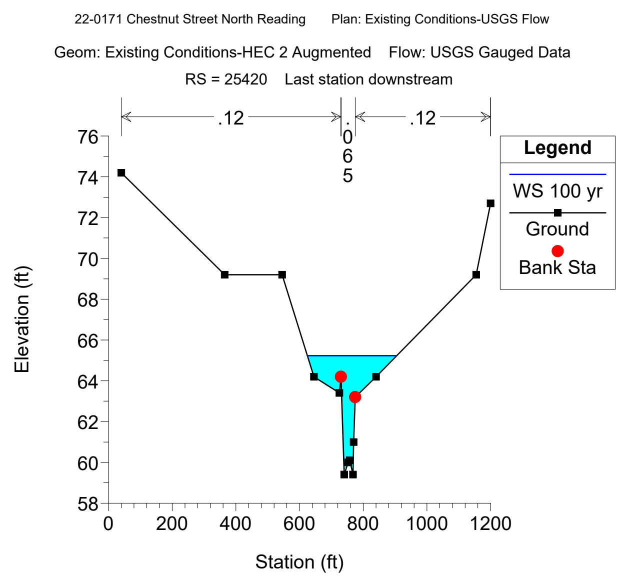
22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 27173
.15
.
0
6
5
.15
80
75
70
65
60
55
0
500
1000
1500
2000
2500
Elevation (ft)
Station (ft)
Legend
WS 100 yr
Ground
Bank Sta



22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 26942
.
1
2
.
0
6
5
.12
72
70
68
66
64
62
60
58
0
200
400
600
800
1000
Elevation (ft)
Station (ft)
Legend
WS 100 yr
Ground
Bank Sta



22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 26796
.
1
2
.
0
6
5
.12
72
70
68
66
64
62
60
58
0
200
400
600
800
1000
Elevation (ft)
Station (ft)
Legend
WS 100 yr
Ground
Bank Sta



22-0171 Chestnut Street North Reading Plan: Existing Conditions-USGS Flow
Geom: Existing Conditions-HEC 2 Augmented Flow: USGS Gauged Data
RS = 25420 Last station downstream
.12
.
0
6
5
.12
76
74
72
70
68
66
64
62
60
58
0
200
400
600
800
1000
1200
Elevation (ft)
Station (ft)
Legend
WS 100 yr
Ground
Bank Sta

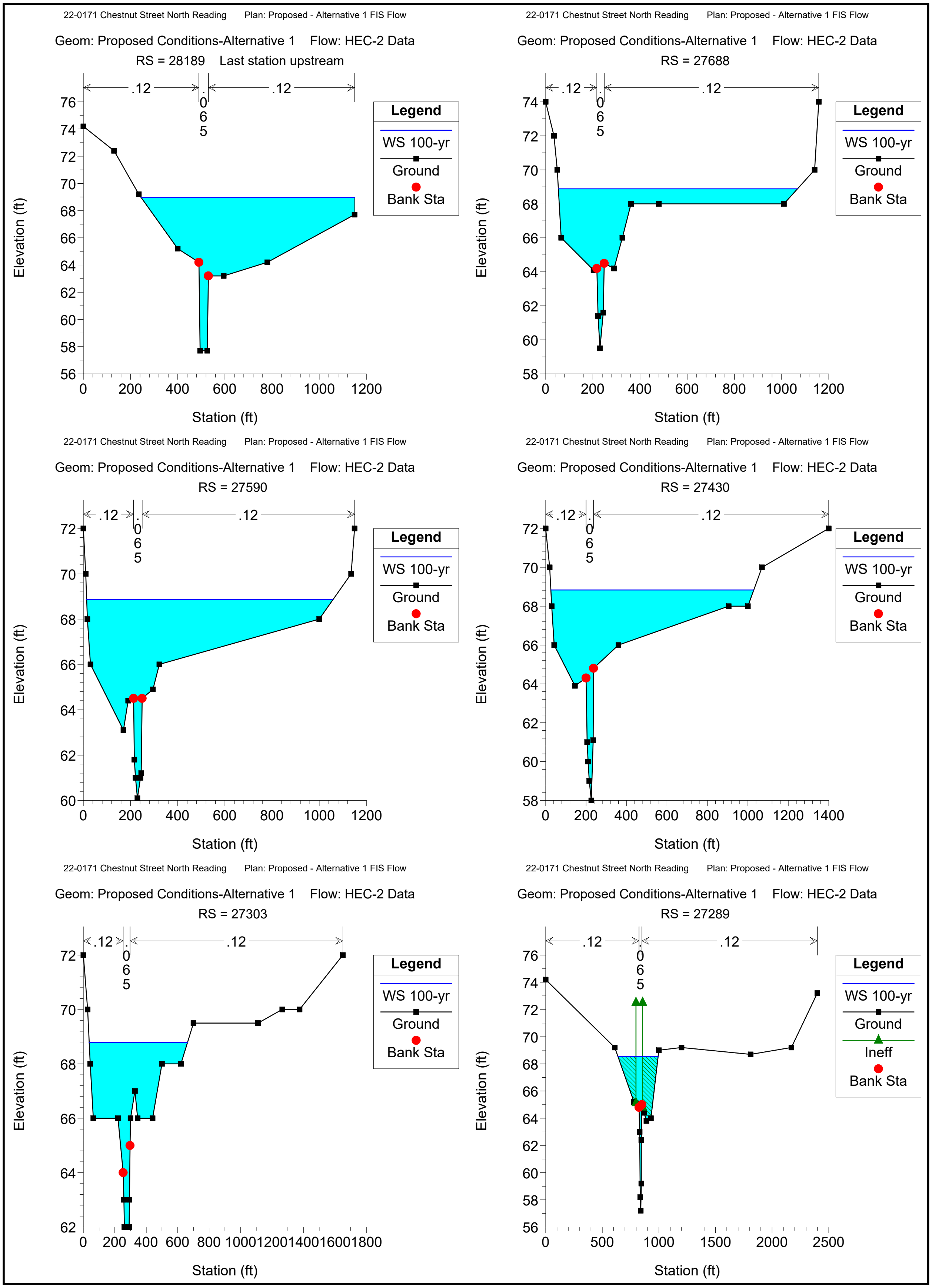
7.3.3 Alternative 1 (48’ Span) – FIS Flow

7.3.3 - Alternative 1 (48' Span) - FIS Flow

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
N.Reading	28189	100-yr	1035	57.7	68.96		68.96	0.000059	0.77	3556.56	905.1	0.04
N.Reading	27688	100-yr	1035	59.5	68.88		68.9	0.000393	1.69	1833.82	1013.44	0.11
N.Reading	27590	100-yr	1035	60.1	68.87		68.87	0.000164	1.09	2683.56	1044.42	0.07
N.Reading	27430	100-yr	1035	58	68.84		68.85	0.000168	1.18	2527.58	1003.47	0.07
N.Reading	27303	100-yr	1035	62	68.79		68.81	0.000493	1.72	1475.89	624.71	0.12
N.Reading	27289	100-yr	1035	57.2	68.53	64.46	68.77	0.003216	4.33	314.47	355.03	0.27
N.Reading	27263		Bridge									
N.Reading	27223	100-yr	1035	62.1	68.33	65.15	68.59	0.000486	4.41	455.31	182.37	0.31
N.Reading	27173	100-yr	1035	58.7	68.4		68.45	0.001134	2.38	1196.41	884.84	0.17
N.Reading	26942	100-yr	1035	59.6	67.85		68.03	0.002531	3.67	398.56	138.76	0.26
N.Reading	26796	100-yr	1035	58.1	67.75	63.74	67.79	0.000888	2.26	1295.79	740.5	0.15
N.Reading	25420	100-yr	1035	59.4	66.14	62.94	66.22	0.001502	2.72	766.01	355.73	0.2

Plan: Proposed - Alternative 1 FIS Flow Ipswich River N.Reading RS: 27263.0 Profile: 100-yr

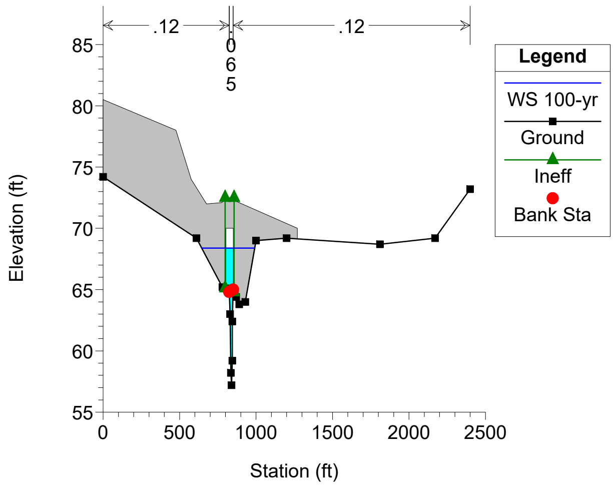
E.G. US. (ft)	68.77	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	68.53	E.G. Elev (ft)	68.71	68.66
Q Total (cfs)	1035.00	W.S. Elev (ft)	68.39	68.29
Q Bridge (cfs)	1035.00	Crit W.S. (ft)	64.46	65.17
Q Weir (cfs)		Max Chl Dpth (ft)	11.19	6.19
Weir Sta Lft (ft)		Vel Total (ft/s)	3.85	3.60
Weir Sta Rgt (ft)		Flow Area (sq ft)	268.53	287.69
Weir Submerg		Froude # Chl	0.24	0.34
Weir Max Depth (ft)		Specif Force (cu ft)	1088.50	1017.21
Min El Weir Flow (ft)	72.42	Hydr Depth (ft)	5.59	5.99
Min El Prs (ft)	70.00	W.P. Total (ft)	61.30	58.61
Delta EG (ft)	0.19	Conv. Total (cfs)	16257.7	41426.8
Delta WS (ft)	0.20	Top Width (ft)	48.00	48.00
BR Open Area (sq ft)	346.01	Frctn Loss (ft)	0.03	0.01
BR Open Vel (ft/s)	3.85	C & E Loss (ft)	0.01	0.05
BR Sluice Coef		Shear Total (lb/sq ft)	1.11	0.19
BR Sel Method	Energy only	Power Total (lb/ft s)	4.27	0.69



22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow
Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 28189 Last station upstream
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow
Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 27688
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow
Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 27590
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow
Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 27430
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow
Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 27303
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow
Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 27289
.12
.065
.12
Legend
WS 100-yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

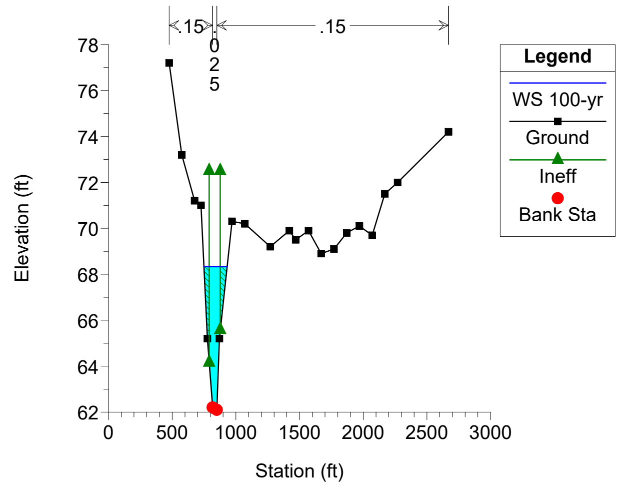
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow

Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 27263.0 BR Chestnut Street



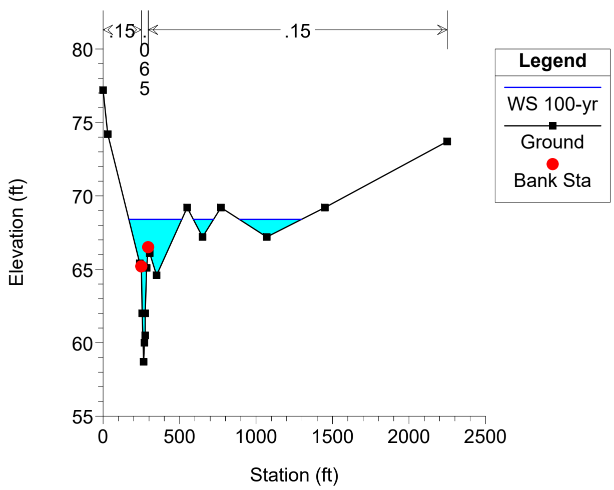
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow

Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 27223



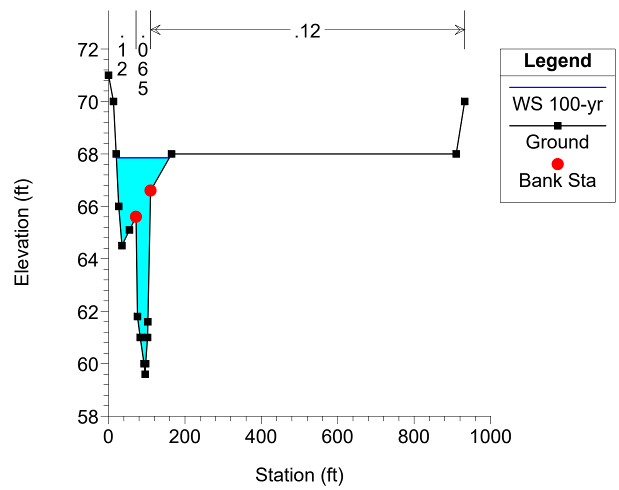
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow

Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 27173



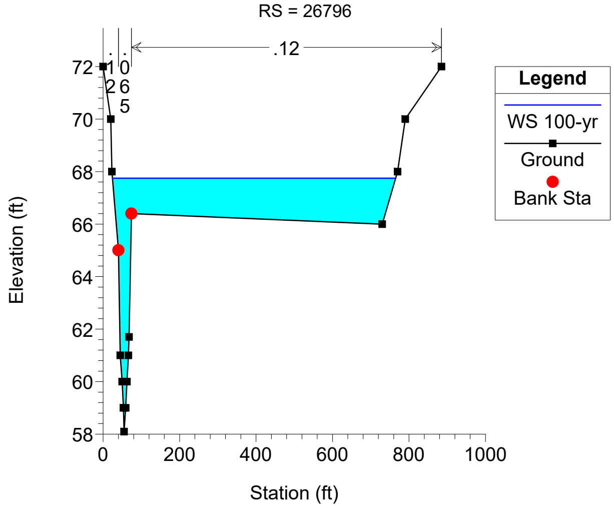
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow

Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 26942



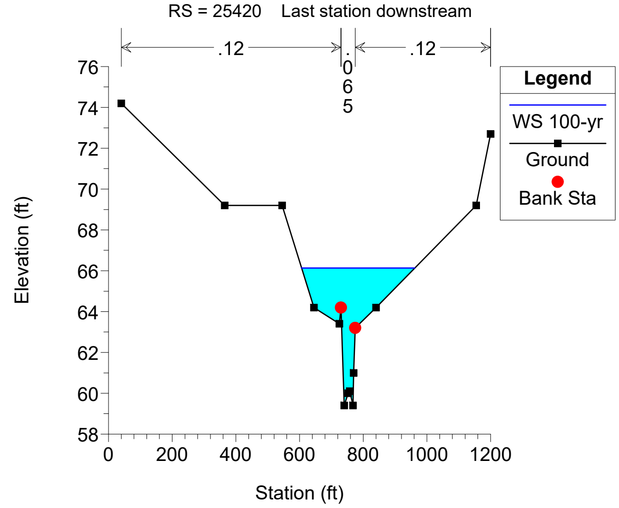
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow

Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 26796



22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 FIS Flow

Geom: Proposed Conditions-Alternative 1 Flow: HEC-2 Data
RS = 25420 Last station downstream



7.3.4 Alternative 1 (48’ Span) – USGS PeakFQ Flows

7.3.4 Alternative 1 (48' Span) - USGS PeakFQ Flows

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
N.Reading	28189	10 yr	688	57.7	68.05		68.05	0.000052	0.68	2750.3	867.58	0.04
N.Reading	28189	25 yr	895	57.7	68.61		68.62	0.000056	0.74	3244.6	890.77	0.04
N.Reading	28189	50 yr	1071	57.7	69.03		69.03	0.00006	0.78	3618.87	907.93	0.04
N.Reading	28189	100 yr	1260	57.7	69.44		69.44	0.000063	0.82	3994.74	922.85	0.04
N.Reading	27688	10 yr	688	59.5	67.98		68	0.000392	1.55	961.45	303.95	0.11
N.Reading	27688	25 yr	895	59.5	68.53		68.55	0.00045	1.75	1481.48	989.07	0.11
N.Reading	27688	50 yr	1071	59.5	68.95		68.97	0.000389	1.69	1903.33	1018.18	0.11
N.Reading	27688	100 yr	1260	59.5	69.36		69.38	0.00034	1.64	2330.88	1046.85	0.1
N.Reading	27590	10 yr	688	60.1	67.96		67.97	0.000196	1.1	1764.91	968.24	0.07
N.Reading	27590	25 yr	895	60.1	68.51		68.52	0.000177	1.1	2320.39	1019.43	0.07
N.Reading	27590	50 yr	1071	60.1	68.93		68.94	0.000165	1.1	2754.99	1049.27	0.07
N.Reading	27590	100 yr	1260	60.1	69.35		69.35	0.000155	1.11	3195.71	1078.68	0.07
N.Reading	27430	10 yr	688	58	67.93		67.94	0.000184	1.15	1637.36	854.23	0.07
N.Reading	27430	25 yr	895	58	68.48		68.49	0.000179	1.19	2174.83	989.31	0.07
N.Reading	27430	50 yr	1071	58	68.91		68.91	0.000168	1.19	2596.09	1006.2	0.07
N.Reading	27430	100 yr	1260	58	69.32		69.33	0.00016	1.2	3017.98	1022.84	0.07
N.Reading	27303	10 yr	688	62	67.87		67.9	0.000543	1.63	945.77	451.02	0.12
N.Reading	27303	25 yr	895	62	68.43		68.46	0.000536	1.73	1256.54	602.6	0.12
N.Reading	27303	50 yr	1071	62	68.86		68.88	0.000493	1.73	1518.52	628.91	0.12
N.Reading	27303	100 yr	1260	62	69.27		69.3	0.000458	1.74	1787.05	654.78	0.12
N.Reading	27289	10 yr	688	57.2	67.72	62.93	67.87	0.00224	3.36	266.69	309.27	0.23
N.Reading	27289	25 yr	895	57.2	68.22	63.93	68.42	0.002852	3.97	295.89	337.23	0.26
N.Reading	27289	50 yr	1071	57.2	68.59	64.59	68.84	0.003345	4.44	317.72	358.13	0.28
N.Reading	27289	100 yr	1260	57.2	68.94	65.55	69.25	0.003856	4.91	338.84	852.51	0.3
N.Reading	27263		Bridge									
N.Reading	27223	10 yr	688	62.1	67.61	64.49	67.76	0.00033	3.35	393.03	162.16	0.25
N.Reading	27223	25 yr	895	62.1	68.06	64.9	68.27	0.000426	4.01	431.42	174.62	0.29
N.Reading	27223	50 yr	1071	62.1	68.37	65.2	68.64	0.000508	4.53	458.96	183.55	0.32
N.Reading	27223	100 yr	1260	62.1	68.66	65.52	69	0.000599	5.08	484.37	191.8	0.35
N.Reading	27173	10 yr	688	58.7	67.63		67.69	0.001128	2.17	672.6	490.88	0.17
N.Reading	27173	25 yr	895	58.7	68.1		68.16	0.00117	2.34	957.64	732.04	0.17
N.Reading	27173	50 yr	1071	58.7	68.44		68.5	0.001153	2.42	1239	909.4	0.17
N.Reading	27173	100 yr	1260	58.7	68.77		68.82	0.001114	2.46	1560.96	1077.1	0.17
N.Reading	26942	10 yr	688	59.6	67.25		67.36	0.001716	2.82	322.16	112.77	0.21
N.Reading	26942	25 yr	895	59.6	67.61		67.76	0.002239	3.36	366.15	128.38	0.24
N.Reading	26942	50 yr	1071	59.6	67.88		68.07	0.00267	3.78	401.59	139.69	0.27
N.Reading	26942	100 yr	1260	59.6	68.13	64.69	68.35	0.003102	4.18	531.85	891.83	0.29
N.Reading	26796	10 yr	688	58.1	67.1		67.15	0.001006	2.25	820.84	723.86	0.16
N.Reading	26796	25 yr	895	58.1	67.48		67.53	0.000957	2.28	1100.58	733.71	0.16
N.Reading	26796	50 yr	1071	58.1	67.76		67.81	0.000928	2.31	1309.02	740.96	0.16
N.Reading	26796	100 yr	1260	58.1	68.03	64.27	68.07	0.000912	2.35	1509.39	747.39	0.16
N.Reading	25420	10 yr	688	59.4	64.18	62.22	64.41	0.005608	3.95	229.02	191.66	0.36
N.Reading	25420	25 yr	895	59.4	64.62	62.66	64.88	0.005605	4.26	323.08	230.26	0.37
N.Reading	25420	50 yr	1071	59.4	64.94	63	65.2	0.005603	4.47	398.99	256.17	0.37
N.Reading	25420	100 yr	1260	59.4	65.23	63.36	65.5	0.005602	4.67	477.68	280.5	0.38

Plan: Proposed Alternative 1 - USGS Flow   Ipswich River   N.Reading RS: 27263.0   Profile: 10 yr

E.G. US. (ft)	67.87	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	67.72	E.G. Elev (ft)	67.83	67.80
Q Total (cfs)	688.00	W.S. Elev (ft)	67.65	67.60
Q Bridge (cfs)	688.00	Crit W.S. (ft)	62.93	64.47
Q Weir (cfs)		Max Chl Dpth (ft)	10.45	5.50
Weir Sta Lft (ft)		Vel Total (ft/s)	2.95	2.70
Weir Sta Rgt (ft)		Flow Area (sq ft)	232.98	254.39
Weir Submerg		Froude # Chl	0.19	0.27
Weir Max Depth (ft)		Specif Force (cu ft)	832.90	752.12
Min El Weir Flow (ft)	72.42	Hydr Depth (ft)	4.85	5.30
Min El Prs (ft)	70.00	W.P. Total (ft)	59.82	57.22
Delta EG (ft)	0.11	Conv. Total (cfs)	13376.2	33955.2
Delta WS (ft)	0.11	Top Width (ft)	48.00	48.00
BR Open Area (sq ft)	346.01	Frctn Loss (ft)	0.02	0.01
BR Open Vel (ft/s)	2.95	C & E Loss (ft)	0.01	0.03
BR Sluice Coef		Shear Total (lb/sq ft)	0.64	0.11
BR Sel Method	Energy only	Power Total (lb/ft s)	1.90	0.31

Plan: Proposed Alternative 1 - USGS Flow   Ipswich River   N.Reading RS: 27263.0   Profile: 25 yr

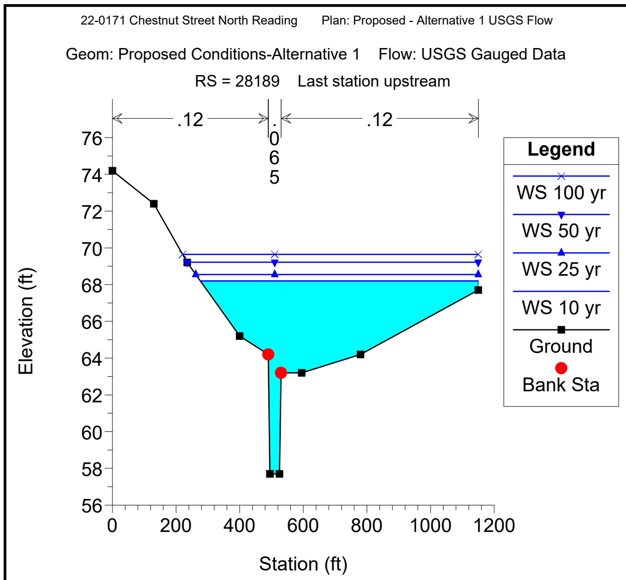
E.G. US. (ft)	68.42	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	68.22	E.G. Elev (ft)	68.36	68.33
Q Total (cfs)	895.00	W.S. Elev (ft)	68.10	68.03
Q Bridge (cfs)	895.00	Crit W.S. (ft)	63.93	64.90
Q Weir (cfs)		Max Chl Dpth (ft)	10.90	5.93
Weir Sta Lft (ft)		Vel Total (ft/s)	3.51	3.25
Weir Sta Rgt (ft)		Flow Area (sq ft)	254.83	274.98
Weir Submerg		Froude # Chl	0.22	0.32
Weir Max Depth (ft)		Specif Force (cu ft)	983.61	909.12
Min El Weir Flow (ft)	72.42	Hydr Depth (ft)	5.31	5.73
Min El Prs (ft)	70.00	W.P. Total (ft)	60.73	58.08
Delta EG (ft)	0.15	Conv. Total (cfs)	15119.7	38505.8
Delta WS (ft)	0.16	Top Width (ft)	48.00	48.00
BR Open Area (sq ft)	346.01	Frctn Loss (ft)	0.03	0.01
BR Open Vel (ft/s)	3.51	C & E Loss (ft)	0.01	0.04
BR Sluice Coef		Shear Total (lb/sq ft)	0.92	0.16
BR Sel Method	Energy only	Power Total (lb/ft s)	3.22	0.52

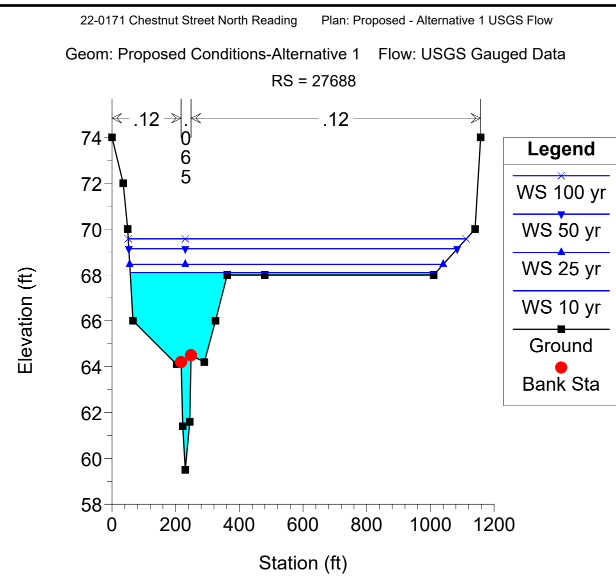
Plan: Proposed Alternative 1 - USGS Flow   Ipswich River   N.Reading RS: 27263.0   Profile: 50 yr

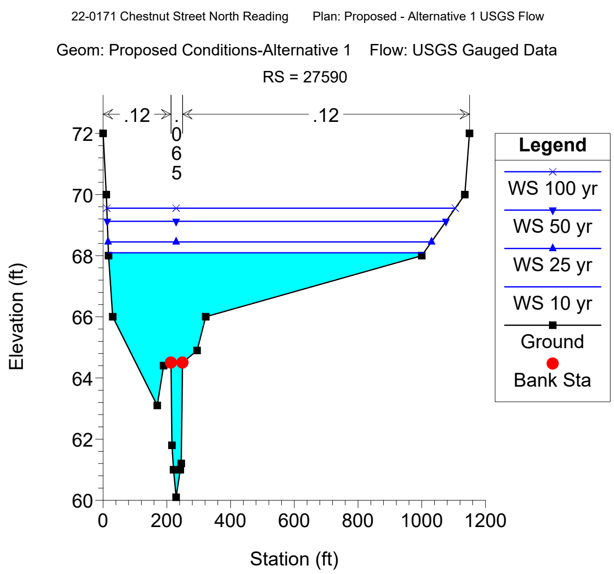
E.G. US. (ft)	68.84	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	68.59	E.G. Elev (ft)	68.77	68.72
Q Total (cfs)	1071.00	W.S. Elev (ft)	68.43	68.33
Q Bridge (cfs)	1071.00	Crit W.S. (ft)	64.59	65.24
Q Weir (cfs)		Max Chl Dpth (ft)	11.23	6.23
Weir Sta Lft (ft)		Vel Total (ft/s)	3.96	3.70
Weir Sta Rgt (ft)		Flow Area (sq ft)	270.73	289.58
Weir Submerg		Froude # Chl	0.24	0.35
Weir Max Depth (ft)		Specif Force (cu ft)	1109.67	1038.36
Min El Weir Flow (ft)	72.42	Hydr Depth (ft)	5.64	6.03
Min El Prs (ft)	70.00	W.P. Total (ft)	61.40	58.68
Delta EG (ft)	0.20	Conv. Total (cfs)	16443.4	41866.9
Delta WS (ft)	0.21	Top Width (ft)	48.00	48.00
BR Open Area (sq ft)	346.01	Frctn Loss (ft)	0.04	0.02
BR Open Vel (ft/s)	3.96	C & E Loss (ft)	0.02	0.06
BR Sluice Coef		Shear Total (lb/sq ft)	1.17	0.20
BR Sel Method	Energy only	Power Total (lb/ft s)	4.62	0.75

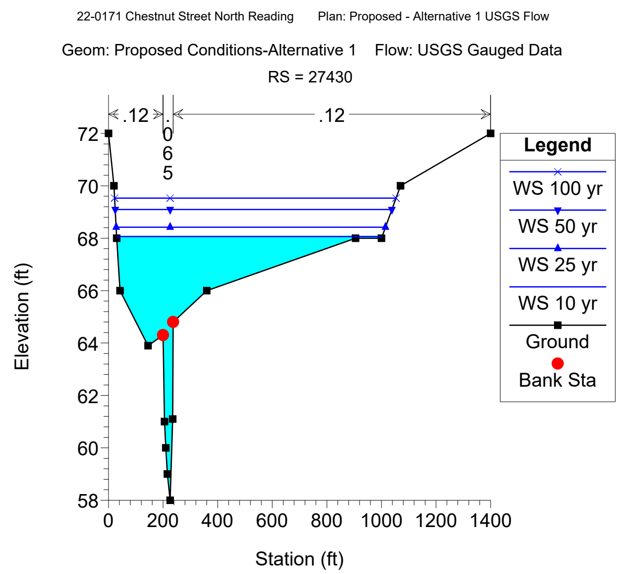
Plan: Proposed Alternative 1 - USGS Flow   Ipswich River   N.Reading RS: 27263.0   Profile: 100 yr

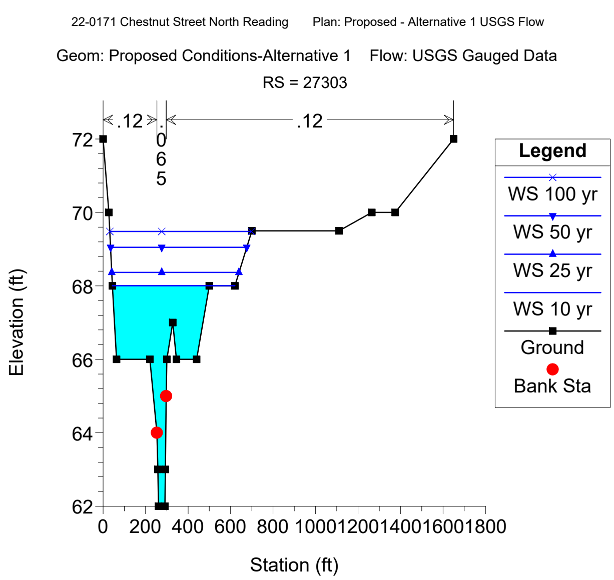
E.G. US. (ft)	69.25	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	68.94	E.G. Elev (ft)	69.16	69.10
Q Total (cfs)	1260.00	W.S. Elev (ft)	68.74	68.61
Q Bridge (cfs)	1260.00	Crit W.S. (ft)	65.42	65.59
Q Weir (cfs)		Max Chl Dpth (ft)	11.54	6.51
Weir Sta Lft (ft)		Vel Total (ft/s)	4.41	4.16
Weir Sta Rgt (ft)		Flow Area (sq ft)	285.65	302.86
Weir Submerg		Froude # Chl	0.27	0.39
Weir Max Depth (ft)		Specif Force (cu ft)	1243.34	1173.42
Min El Weir Flow (ft)	72.42	Hydr Depth (ft)	5.95	6.31
Min El Prs (ft)	70.00	W.P. Total (ft)	62.02	59.24
Delta EG (ft)	0.25	Conv. Total (cfs)	17727.3	45018.8
Delta WS (ft)	0.28	Top Width (ft)	48.00	48.00
BR Open Area (sq ft)	346.01	Frctn Loss (ft)	0.04	0.02
BR Open Vel (ft/s)	4.41	C & E Loss (ft)	0.02	0.08
BR Sluice Coef		Shear Total (lb/sq ft)	1.45	0.25
BR Sel Method	Energy only	Power Total (lb/ft s)	6.41	1.04

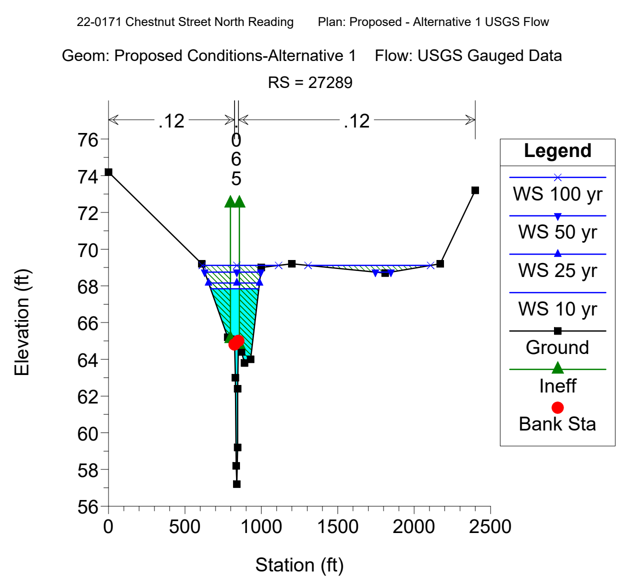

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 28189 Last station upstream
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

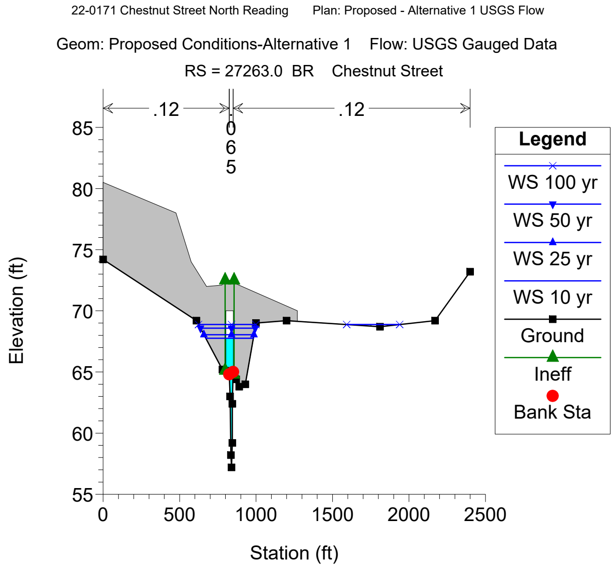

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 27688
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

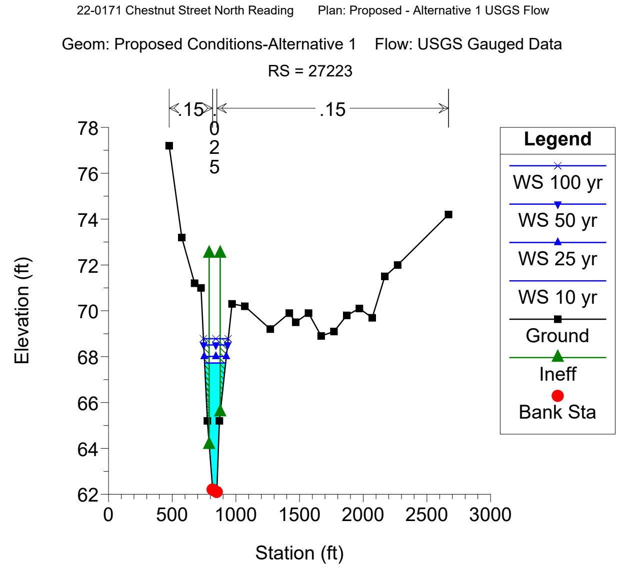

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 27590
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

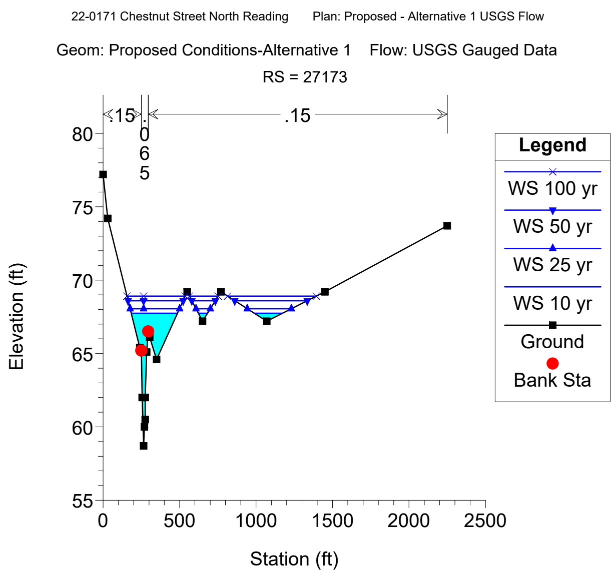

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 27430
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

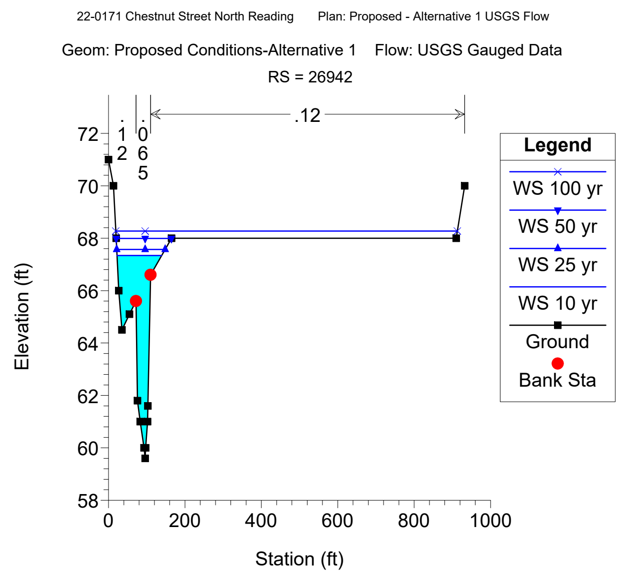

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 27303
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

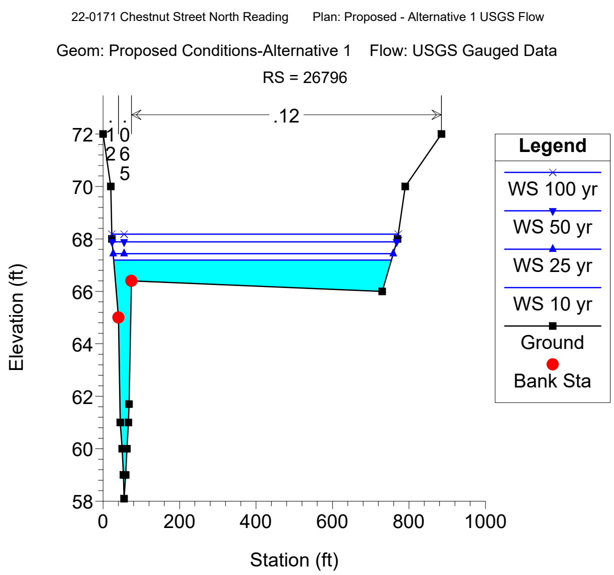

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 27289
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

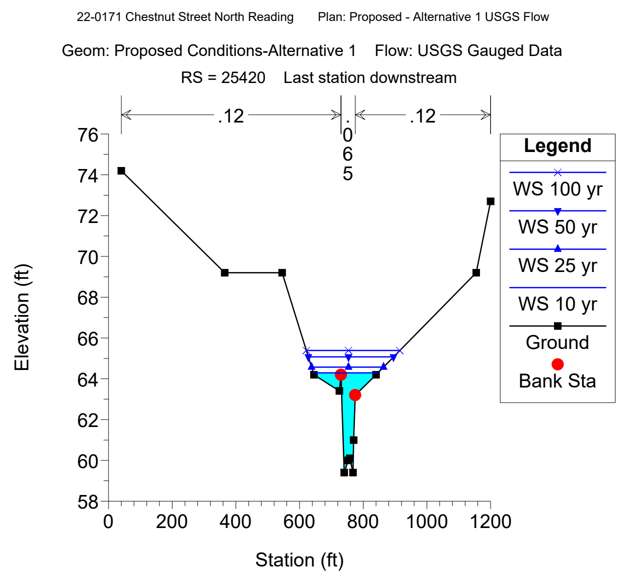

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 27263.0 BR Chestnut Street
.12
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 27223
.15
.15
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 27173
.15
.15
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 26942
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 26796
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 1 USGS Flow
Geom: Proposed Conditions-Alternative 1 Flow: USGS Gauged Data
RS = 25420 Last station downstream
.12
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

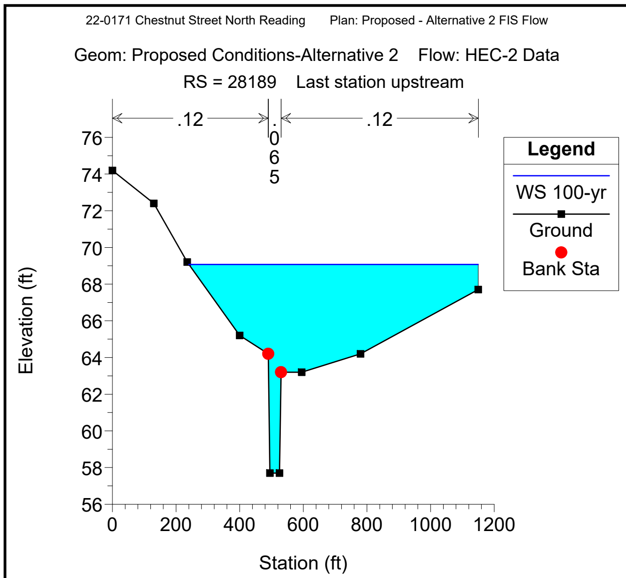
7.3.5 Alternative 2 (34’ Span) – FIS Flow

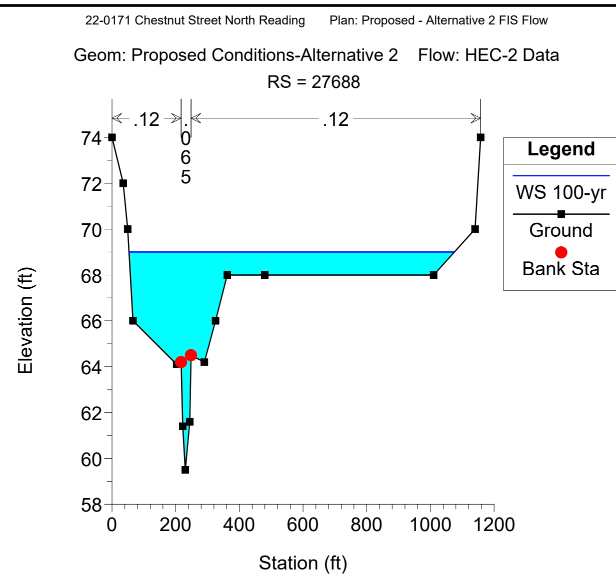
7.3.5 Alternative 2 (34' Span) - FIS Flow

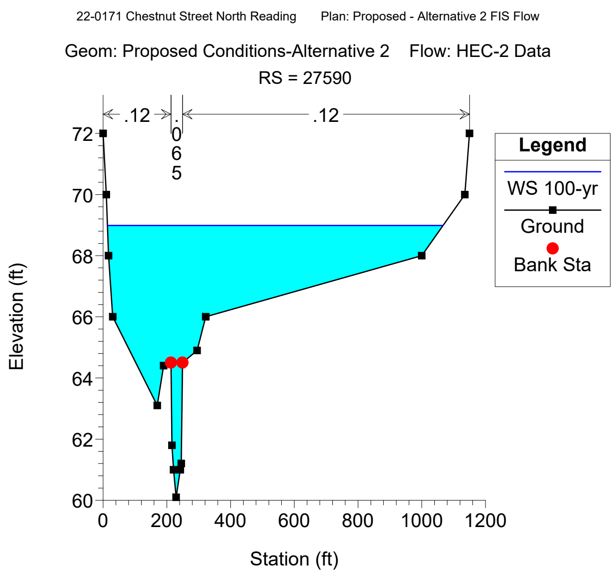
Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
N.Reading	28189	100-yr	1035	57.7	69.07		69.07	0.000055	0.75	3657.21	909.67	0.04
N.Reading	27688	100-yr	1035	59.5	69		69.02	0.000342	1.59	1955.07	1021.69	0.1
N.Reading	27590	100-yr	1035	60.1	68.99		68.99	0.000146	1.04	2809.98	1052.98	0.07
N.Reading	27430	100-yr	1035	58	68.96		68.97	0.000149	1.13	2652.05	1008.42	0.07
N.Reading	27303	100-yr	1035	62	68.92		68.94	0.000433	1.63	1557.21	632.7	0.11
N.Reading	27289	100-yr	1035	57.2	68.67	64.46	68.9	0.002986	4.22	322.85	363.05	0.27
N.Reading	27263		Bridge									
N.Reading	27223	100-yr	1035	62.1	68.33	65.15	68.59	0.000486	4.41	455.3	182.37	0.31
N.Reading	27173	100-yr	1035	58.7	68.4		68.45	0.001135	2.38	1196.36	884.81	0.17
N.Reading	26942	100-yr	1035	59.6	67.85		68.03	0.002531	3.67	398.55	138.76	0.26
N.Reading	26796	100-yr	1035	58.1	67.75	63.74	67.79	0.000888	2.26	1295.72	740.5	0.15
N.Reading	25420	100-yr	1035	59.4	66.14	62.94	66.22	0.001502	2.72	766.01	355.73	0.2

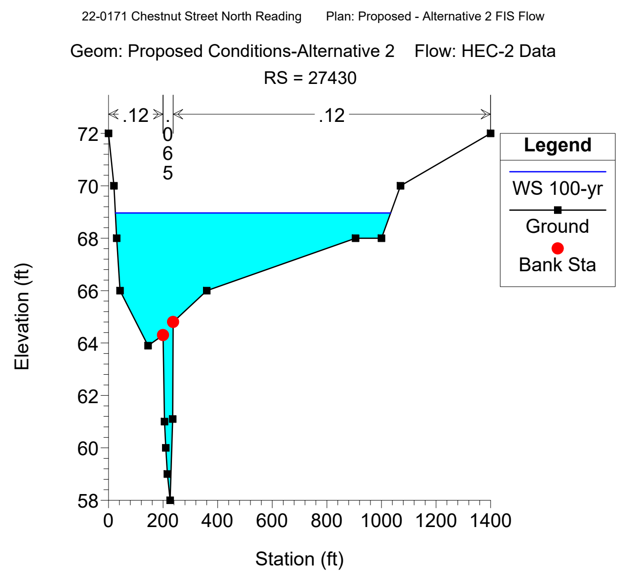
Plan: Proposed - Alternative 2 FIS Flow   Ipswich River   N.Reading RS: 27263.0   Profile: 100-yr

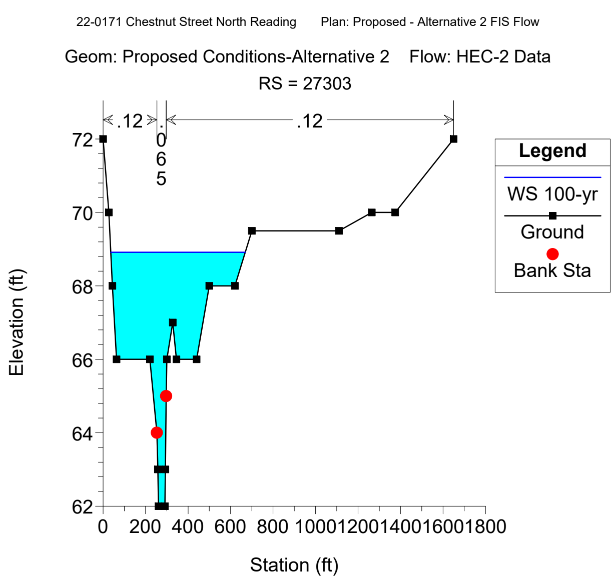
E.G. US. (ft)	68.90	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	68.67	E.G. Elev (ft)	68.76	68.69
Q Total (cfs)	1035.00	W.S. Elev (ft)	68.27	68.26
Q Bridge (cfs)	1035.00	Crit W.S. (ft)	64.51	65.32
Q Weir (cfs)		Max Chl Dpth (ft)	11.07	6.16
Weir Sta Lft (ft)		Vel Total (ft/s)	5.01	4.98
Weir Sta Rgt (ft)		Flow Area (sq ft)	206.73	207.69
Weir Submerg		Froude # Chl	0.30	0.37
Weir Max Depth (ft)		Specif Force (cu ft)	969.69	802.80
Min El Weir Flow (ft)	72.36	Hydr Depth (ft)	6.08	6.11
Min El Prs (ft)	70.30	W.P. Total (ft)	51.10	46.04
Delta EG (ft)	0.32	Conv. Total (cfs)	11324.2	39188.6
Delta WS (ft)	0.34	Top Width (ft)	34.00	34.00
BR Open Area (sq ft)	275.65	Frctn Loss (ft)	0.04	0.02
BR Open Vel (ft/s)	5.01	C & E Loss (ft)	0.03	0.08
BR Sluice Coef		Shear Total (lb/sq ft)	2.11	0.20
BR Sel Method	Energy only	Power Total (lb/ft s)	10.56	0.98

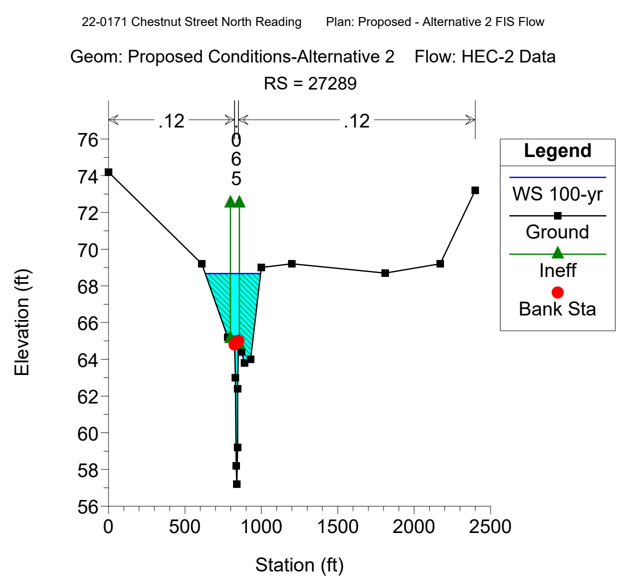

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 28189 Last station upstream
.12
.065
.12
Elevation (ft)
Station (ft)
Legend
WS 100-yr
Ground
Bank Sta

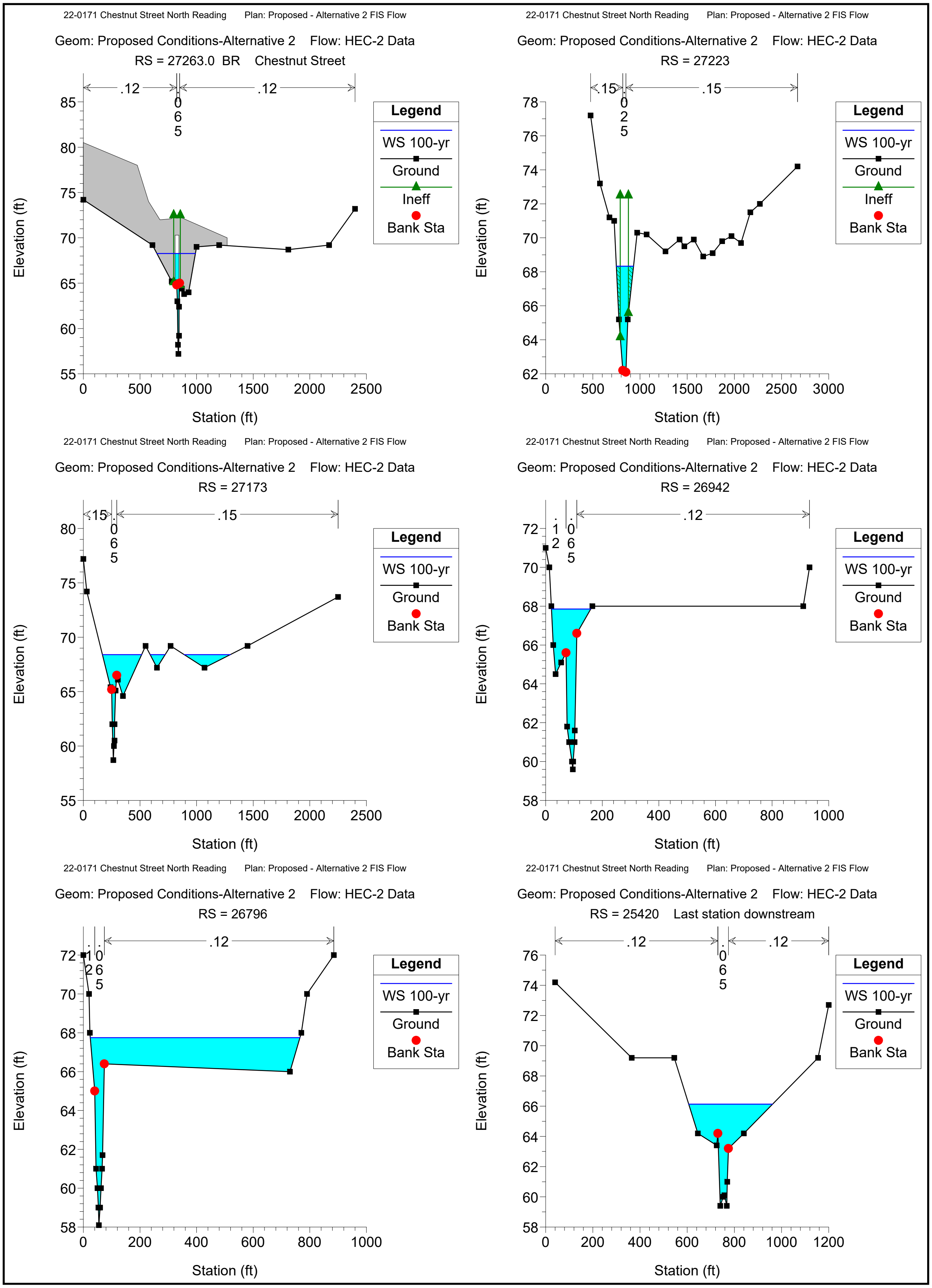

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 27688
.12
.065
.12
Elevation (ft)
Station (ft)
Legend
WS 100-yr
Ground
Bank Sta


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 27590
.12
.065
.12
Elevation (ft)
Station (ft)
Legend
WS 100-yr
Ground
Bank Sta


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 27430
.12
.065
.12
Elevation (ft)
Station (ft)
Legend
WS 100-yr
Ground
Bank Sta


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 27303
.12
.065
.12
Elevation (ft)
Station (ft)
Legend
WS 100-yr
Ground
Bank Sta


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 27289
.12
.065
.12
Elevation (ft)
Station (ft)
Legend
WS 100-yr
Ground
Ineff
Bank Sta


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 27263.0 BR Chestnut Street
.12
.065
.12
Legend
WS 100-yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 27223
.15
.025
.15
Legend
WS 100-yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 27173
.15
.065
.15
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 26942
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 26796
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 FIS Flow
Geom: Proposed Conditions-Alternative 2 Flow: HEC-2 Data
RS = 25420 Last station downstream
.12
.065
.12
Legend
WS 100-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

7.3.6 Alternative 2 (34’ Span) – USGS PeakFQ Flows

7.3.6 Alternative 2 (34' Span) - USGS PeakFQ Flows

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
N.Reading	28189	10 yr	688	57.7	68.12		68.12	0.000049	0.66	2812.55	870.53	0.04
N.Reading	28189	25 yr	895	57.7	68.7		68.7	0.000053	0.72	3323.87	894.43	0.04
N.Reading	28189	50 yr	1071	57.7	69.15		69.15	0.000055	0.76	3725.86	912.78	0.04
N.Reading	28189	100 yr	1260	57.7	69.59		69.59	0.000057	0.79	4135.16	927.83	0.04
N.Reading	27688	10 yr	688	59.5	68.04		68.07	0.000494	1.75	1005.05	955.13	0.12
N.Reading	27688	25 yr	895	59.5	68.62		68.64	0.000399	1.66	1577.2	995.75	0.11
N.Reading	27688	50 yr	1071	59.5	69.07		69.09	0.000337	1.59	2032.28	1026.91	0.1
N.Reading	27688	100 yr	1260	59.5	69.52		69.54	0.000288	1.52	2500.51	1058.01	0.09
N.Reading	27590	10 yr	688	60.1	68.02		68.03	0.000182	1.06	1830.55	984.73	0.07
N.Reading	27590	25 yr	895	60.1	68.61		68.62	0.000159	1.05	2420.26	1026.37	0.07
N.Reading	27590	50 yr	1071	60.1	69.06		69.07	0.000146	1.05	2889.46	1058.33	0.07
N.Reading	27590	100 yr	1260	60.1	69.51		69.52	0.000135	1.04	3372.44	1090.25	0.06
N.Reading	27430	10 yr	688	58	67.99		68	0.000172	1.12	1697.14	873.5	0.07
N.Reading	27430	25 yr	895	58	68.58		68.59	0.000161	1.14	2274.63	993.34	0.07
N.Reading	27430	50 yr	1071	58	69.04		69.04	0.000149	1.13	2728.16	1011.44	0.07
N.Reading	27430	100 yr	1260	58	69.49		69.49	0.000138	1.13	3188.9	1029.5	0.06
N.Reading	27303	10 yr	688	62	67.95		67.97	0.000501	1.58	978.76	453.9	0.12
N.Reading	27303	25 yr	895	62	68.54		68.56	0.000478	1.65	1320.81	609.16	0.12
N.Reading	27303	50 yr	1071	62	68.99		69.01	0.000431	1.64	1605.12	637.37	0.11
N.Reading	27303	100 yr	1260	62	69.45		69.47	0.000393	1.64	1901.17	665.47	0.11
N.Reading	27289	10 yr	688	57.2	67.8	62.93	67.94	0.002139	3.31	271.25	313.64	0.22
N.Reading	27289	25 yr	895	57.2	68.33	63.93	68.53	0.002677	3.88	302.66	343.72	0.25
N.Reading	27289	50 yr	1071	57.2	68.74	64.59	68.98	0.003094	4.32	326.61	438.88	0.27
N.Reading	27289	100 yr	1260	57.2	69.14	65.55	69.43	0.003504	4.76	350.3	1377.19	0.29
N.Reading	27263		Bridge									
N.Reading	27223	10 yr	688	62.1	67.61	64.49	67.76	0.00033	3.35	393.03	162.16	0.25
N.Reading	27223	25 yr	895	62.1	68.06	64.9	68.27	0.000426	4.01	431.42	174.62	0.29
N.Reading	27223	50 yr	1071	62.1	68.37	65.2	68.64	0.000508	4.53	458.96	183.55	0.32
N.Reading	27223	100 yr	1260	62.1	68.66	65.52	69	0.000599	5.08	484.38	191.8	0.35
N.Reading	27173	10 yr	688	58.7	67.63		67.69	0.001128	2.17	672.6	490.88	0.17
N.Reading	27173	25 yr	895	58.7	68.1		68.16	0.00117	2.34	957.63	732.04	0.17
N.Reading	27173	50 yr	1071	58.7	68.44		68.5	0.001153	2.42	1238.98	909.39	0.17
N.Reading	27173	100 yr	1260	58.7	68.77		68.82	0.001114	2.46	1560.98	1077.1	0.17
N.Reading	26942	10 yr	688	59.6	67.25		67.36	0.001716	2.82	322.16	112.77	0.21
N.Reading	26942	25 yr	895	59.6	67.61		67.76	0.002239	3.36	366.15	128.38	0.24
N.Reading	26942	50 yr	1071	59.6	67.88		68.07	0.00267	3.78	401.59	139.69	0.27
N.Reading	26942	100 yr	1260	59.6	68.13	64.69	68.35	0.003101	4.18	531.87	891.83	0.29
N.Reading	26796	10 yr	688	58.1	67.1		67.15	0.001006	2.25	820.84	723.86	0.16
N.Reading	26796	25 yr	895	58.1	67.48		67.53	0.000957	2.28	1100.57	733.71	0.16
N.Reading	26796	50 yr	1071	58.1	67.76		67.81	0.000928	2.31	1308.97	740.96	0.16
N.Reading	26796	100 yr	1260	58.1	68.03	64.27	68.07	0.000912	2.35	1509.41	747.39	0.16
N.Reading	25420	10 yr	688	59.4	64.18	62.22	64.41	0.005608	3.95	229.02	191.66	0.36
N.Reading	25420	25 yr	895	59.4	64.62	62.66	64.88	0.005605	4.26	323.08	230.26	0.37
N.Reading	25420	50 yr	1071	59.4	64.94	63	65.2	0.005603	4.47	398.99	256.17	0.37
N.Reading	25420	100 yr	1260	59.4	65.23	63.36	65.5	0.005602	4.67	477.68	280.5	0.38

Plan: Proposed - Alternative 2 USGS Flow   Ipswich River   N.Reading RS: 27263.0   Profile: 10 yr

E.G. US. (ft)	67.94	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	67.80	E.G. Elev (ft)	67.87	67.82
Q Total (cfs)	688.00	W.S. Elev (ft)	67.59	67.58
Q Bridge (cfs)	688.00	Crit W.S. (ft)	62.90	64.56
Q Weir (cfs)		Max Chl Dpth (ft)	10.39	5.48
Weir Sta Lft (ft)		Vel Total (ft/s)	3.75	3.73
Weir Sta Rgt (ft)		Flow Area (sq ft)	183.54	184.55
Weir Submerg		Froude # Chl	0.23	0.30
Weir Max Depth (ft)		Specif Force (cu ft)	747.61	584.61
Min El Weir Flow (ft)	72.36	Hydr Depth (ft)	5.40	5.43
Min El Prs (ft)	70.30	W.P. Total (ft)	49.73	44.68
Delta EG (ft)	0.18	Conv. Total (cfs)	9723.9	32192.6
Delta WS (ft)	0.18	Top Width (ft)	34.00	34.00
BR Open Area (sq ft)	275.65	Frctn Loss (ft)	0.03	0.01
BR Open Vel (ft/s)	3.75	C & E Loss (ft)	0.02	0.04
BR Sluice Coef		Shear Total (lb/sq ft)	1.15	0.12
BR Sel Method	Energy only	Power Total (lb/ft s)	4.32	0.44

Plan: Proposed - Alternative 2 USGS Flow   Ipswich River   N.Reading RS: 27263.0   Profile: 25 yr

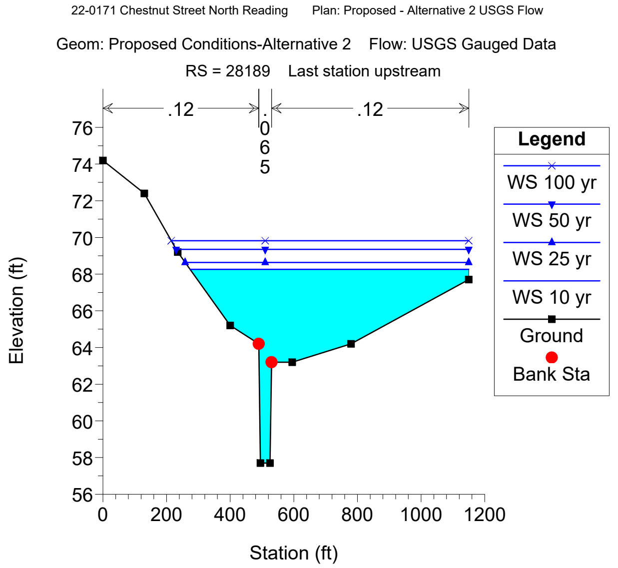
E.G. US. (ft)	68.53	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	68.33	E.G. Elev (ft)	68.41	68.35
Q Total (cfs)	895.00	W.S. Elev (ft)	68.01	68.00
Q Bridge (cfs)	895.00	Crit W.S. (ft)	63.92	65.02
Q Weir (cfs)		Max Chl Dpth (ft)	10.81	5.90
Weir Sta Lft (ft)		Vel Total (ft/s)	4.52	4.50
Weir Sta Rgt (ft)		Flow Area (sq ft)	197.90	198.87
Weir Submerg		Froude # Chl	0.27	0.34
Weir Max Depth (ft)		Specif Force (cu ft)	878.40	713.17
Min El Weir Flow (ft)	72.36	Hydr Depth (ft)	5.82	5.85
Min El Prs (ft)	70.30	W.P. Total (ft)	50.58	45.52
Delta EG (ft)	0.26	Conv. Total (cfs)	10704.9	36458.6
Delta WS (ft)	0.28	Top Width (ft)	34.00	34.00
BR Open Area (sq ft)	275.65	Frctn Loss (ft)	0.04	0.01
BR Open Vel (ft/s)	4.52	C & E Loss (ft)	0.03	0.07
BR Sluice Coef		Shear Total (lb/sq ft)	1.71	0.16
BR Sel Method	Energy only	Power Total (lb/ft s)	7.72	0.74

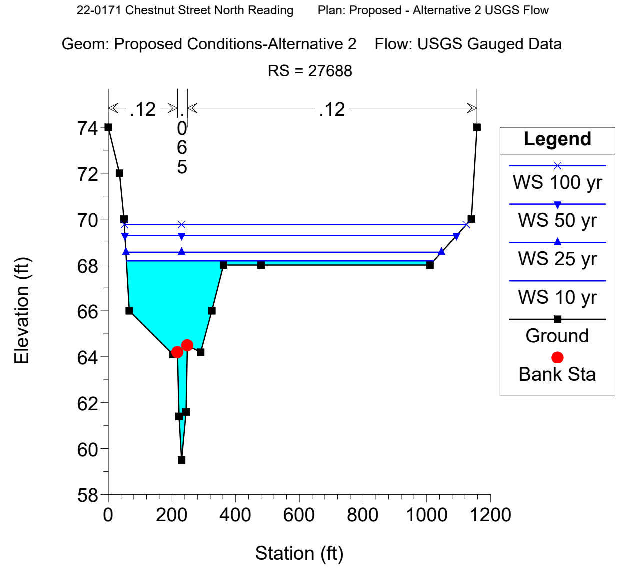
Plan: Proposed - Alternative 2 USGS Flow   Ipswich River   N.Reading RS: 27263.0   Profile: 50 yr

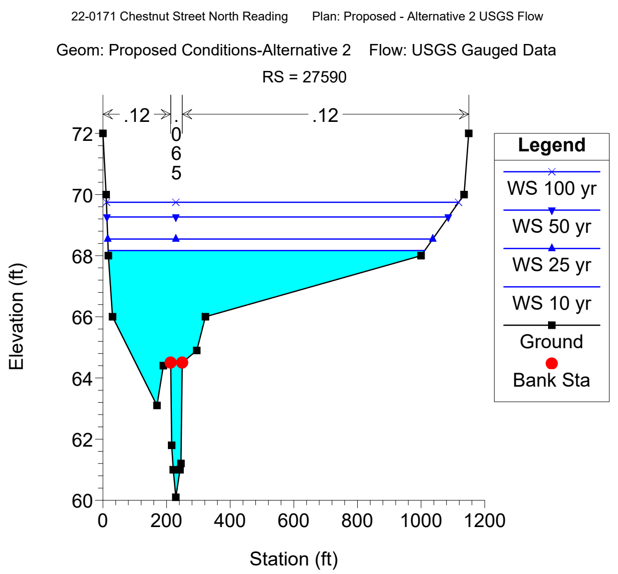
E.G. US. (ft)	68.98	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	68.74	E.G. Elev (ft)	68.83	68.75
Q Total (cfs)	1071.00	W.S. Elev (ft)	68.31	68.30
Q Bridge (cfs)	1071.00	Crit W.S. (ft)	64.65	65.39
Q Weir (cfs)		Max Chl Dpth (ft)	11.11	6.20
Weir Sta Lft (ft)		Vel Total (ft/s)	5.15	5.13
Weir Sta Rgt (ft)		Flow Area (sq ft)	208.02	208.97
Weir Submerg		Froude # Chl	0.31	0.38
Weir Max Depth (ft)		Specif Force (cu ft)	988.90	821.44
Min El Weir Flow (ft)	72.36	Hydr Depth (ft)	6.12	6.15
Min El Prs (ft)	70.30	W.P. Total (ft)	51.17	46.11
Delta EG (ft)	0.33	Conv. Total (cfs)	11415.6	39590.0
Delta WS (ft)	0.36	Top Width (ft)	34.00	34.00
BR Open Area (sq ft)	275.65	Frctn Loss (ft)	0.05	0.02
BR Open Vel (ft/s)	5.15	C & E Loss (ft)	0.03	0.09
BR Sluice Coef		Shear Total (lb/sq ft)	2.23	0.21
BR Sel Method	Energy only	Power Total (lb/ft s)	11.50	1.06

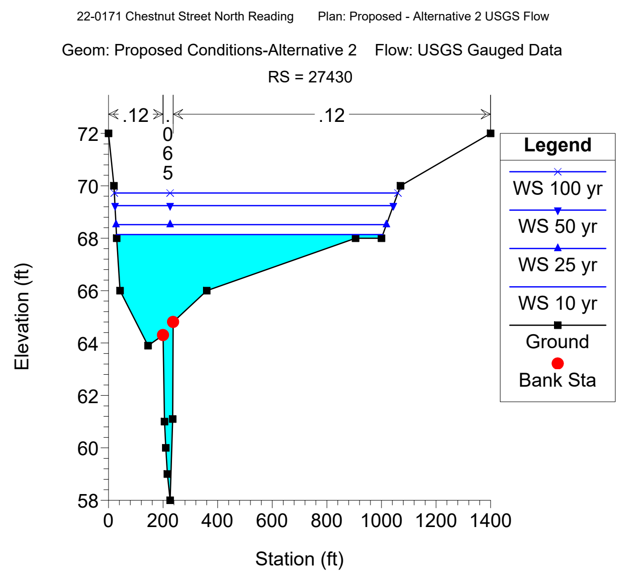
Plan: Proposed - Alternative 2 USGS Flow   Ipswich River   N.Reading RS: 27263.0   Profile: 100 yr

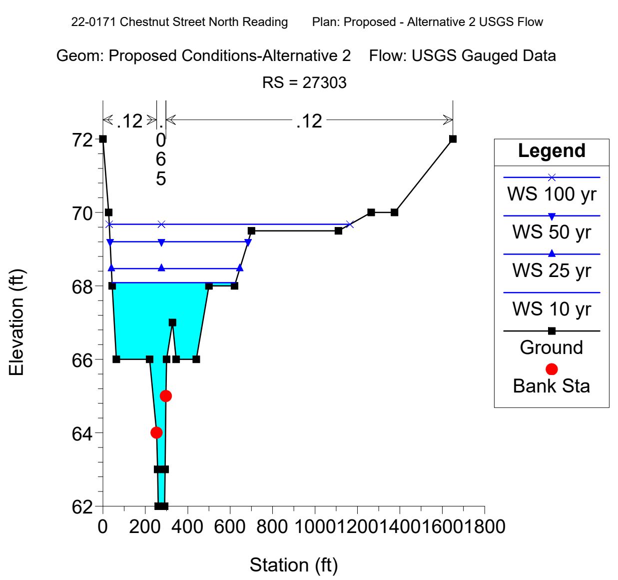
E.G. US. (ft)	69.43	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	69.14	E.G. Elev (ft)	69.24	69.14
Q Total (cfs)	1260.00	W.S. Elev (ft)	68.58	68.57
Q Bridge (cfs)	1260.00	Crit W.S. (ft)	65.58	65.76
Q Weir (cfs)		Max Chl Dpth (ft)	11.38	6.47
Weir Sta Lft (ft)		Vel Total (ft/s)	5.80	5.78
Weir Sta Rgt (ft)		Flow Area (sq ft)	217.15	218.08
Weir Submerg		Froude # Chl	0.34	0.42
Weir Max Depth (ft)		Specif Force (cu ft)	1107.34	937.15
Min El Weir Flow (ft)	72.36	Hydr Depth (ft)	6.39	6.41
Min El Prs (ft)	70.30	W.P. Total (ft)	51.71	46.65
Delta EG (ft)	0.42	Conv. Total (cfs)	12070.1	42504.1
Delta WS (ft)	0.47	Top Width (ft)	34.00	34.00
BR Open Area (sq ft)	275.65	Frctn Loss (ft)	0.06	0.02
BR Open Vel (ft/s)	5.80	C & E Loss (ft)	0.04	0.12
BR Sluice Coef		Shear Total (lb/sq ft)	2.86	0.26
BR Sel Method	Energy only	Power Total (lb/ft s)	16.58	1.48

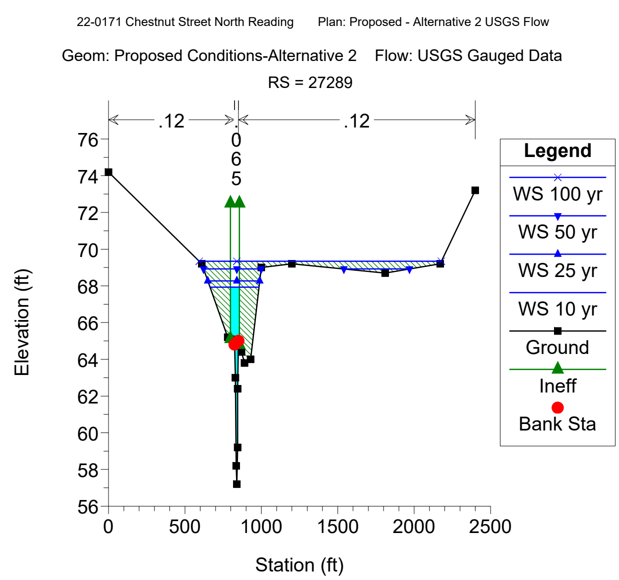

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow
Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data
RS = 28189 Last station upstream
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow
Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data
RS = 27688
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow
Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data
RS = 27590
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow
Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data
RS = 27430
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)

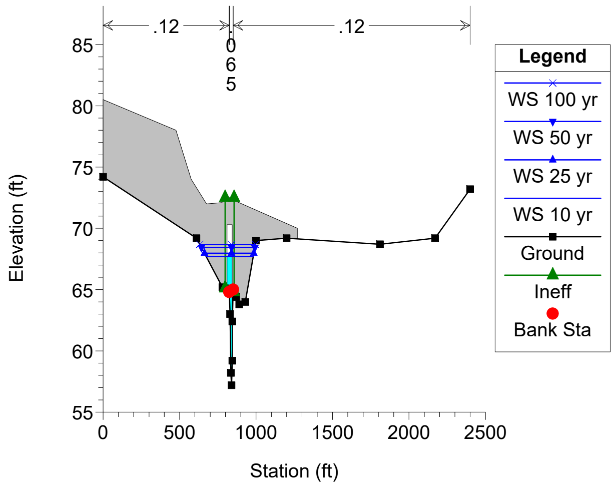

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow
Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data
RS = 27303
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Bank Sta
Elevation (ft)
Station (ft)


22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow
Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data
RS = 27289
.12
.065
.12
Legend
WS 100 yr
WS 50 yr
WS 25 yr
WS 10 yr
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow

Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data

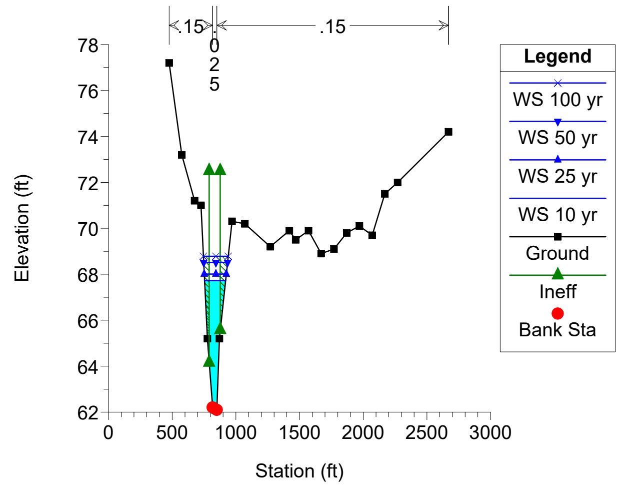
RS = 27263.0 BR Chestnut Street



22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow

Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data

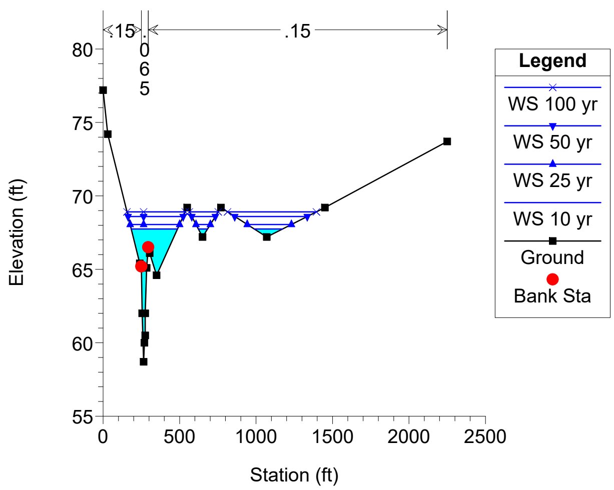
RS = 27223



22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow

Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data

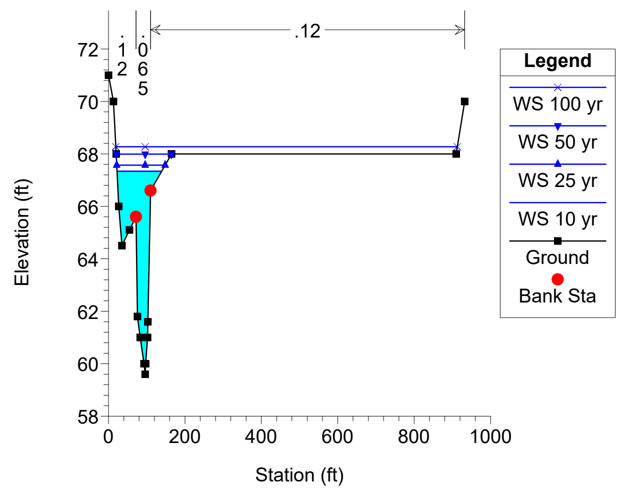
RS = 27173



22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow

Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data

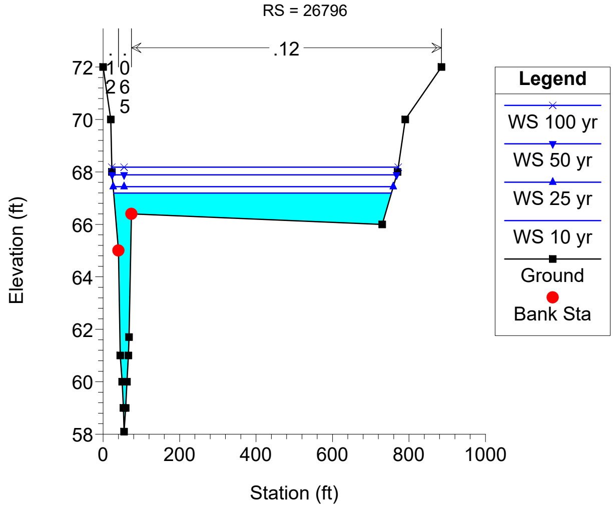
RS = 26942



22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow

Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data

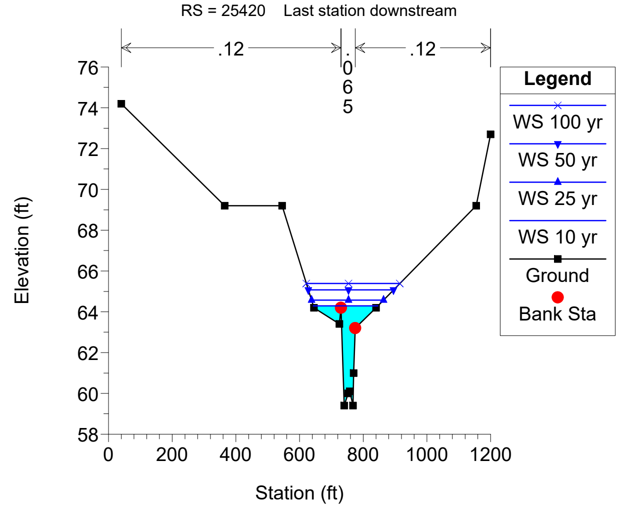
RS = 26796



22-0171 Chestnut Street North Reading Plan: Proposed - Alternative 2 USGS Flow

Geom: Proposed Conditions-Alternative 2 Flow: USGS Gauged Data

RS = 25420 Last station downstream



7.4 Scour Calculations

7.4.1 Scour Sediment Sampling Results
7.4.2 Scour Calculations

7.4.1 Scour Sediment Sampling Results

intertek psi

Professional Service Industries, Inc.
480 Neponset Street, Suite 9C
Canton, MA 02021

Phone: (781) 821-2355
Fax: (781) 821-6276

Report No: MAT:0446516-68-S3
Issue No: 1

Material Test Report

Client: BAY COLONY GROUP
4 SCHOOL ST., P.O. BOX 9136
FOXBORO, MA 02035

CC:

Project: BAY COLONY GROUP - LAB TESTING
CANTON, MA

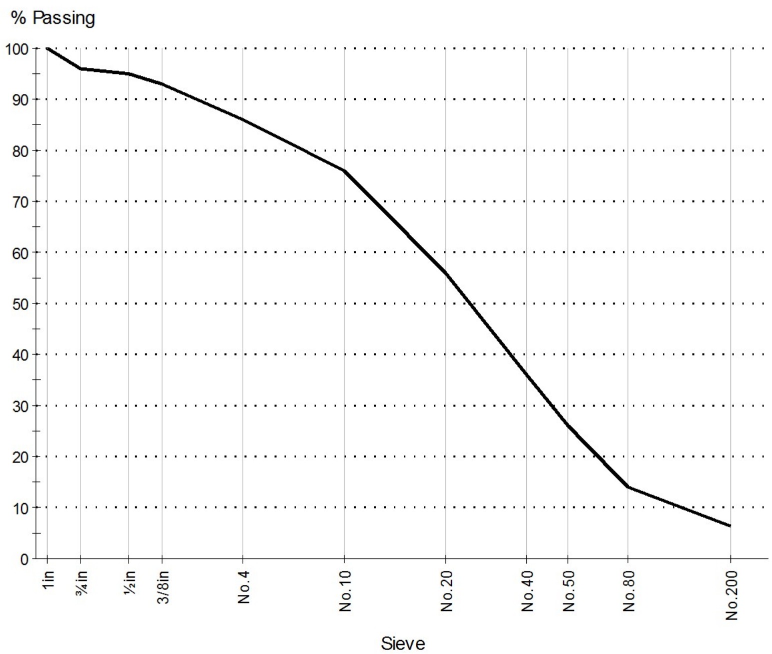
Approved Signatory: Yannick Lastennet (Department Manager)
Date of Issue: 10/20/2022

Sample Details

Sample ID:	0446516-68-S3
Client Sample ID:	
Date Sampled:	
Sampled By:	Others
Specification:	No Spec. Sieve
Supplier:	
Source:	
Material:	
Sampling Method:	
General Location:	Chestnut St. over Ipswich River - North Reading, MA
Location:	50" Upstream
Lift:	

Sample Description:

Particle Size Distribution



COBBLES	GRAVEL		SAND			FINES (6.2%)	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
(0.0%)	(3.6%)	(10.0%)	(10.9%)	(39.4%)	(30.0%)		

Grading: ASTM C 136, ASTM C 117

Date Tested: 10/17/2022
Tested By: Gary Brooks

Sieve Size	% Passing	Limits
1in (25.0mm)	100	
¾in (19.0mm)	96	
½in (12.5mm)	95	
3/8in (9.5mm)	93	
No.4 (4.75mm)	86	
No.10 (2.0mm)	76	
No.20 (850µm)	56	
No.40 (425µm)	36	
No.50 (300µm)	26	
No.80 (180µm)	14	
No.200 (75µm)	6.2	

D85: 4.3564 **D60:** 1.0087 **D50:** 0.6904
D30: 0.3448 **D15:** 0.1878 **D10:** 0.1149
Cu: 8.78 **Cc:** 1.03

Professional Service Industries, Inc.
480 Neponset Street, Suite 9C
Canton, MA 02021

Phone: (781) 821-2355
Fax: (781) 821-6276

Report No: MAT:0446516-68-S1
Issue No: 1

Material Test Report

Approved Signatory: Yannick Lastennet (Department Manager)
Date of Issue: 10/20/2022

Client: BAY COLONY GROUP
4 SCHOOL ST., P.O. BOX 9136
FOXBORO, MA 02035

CC:

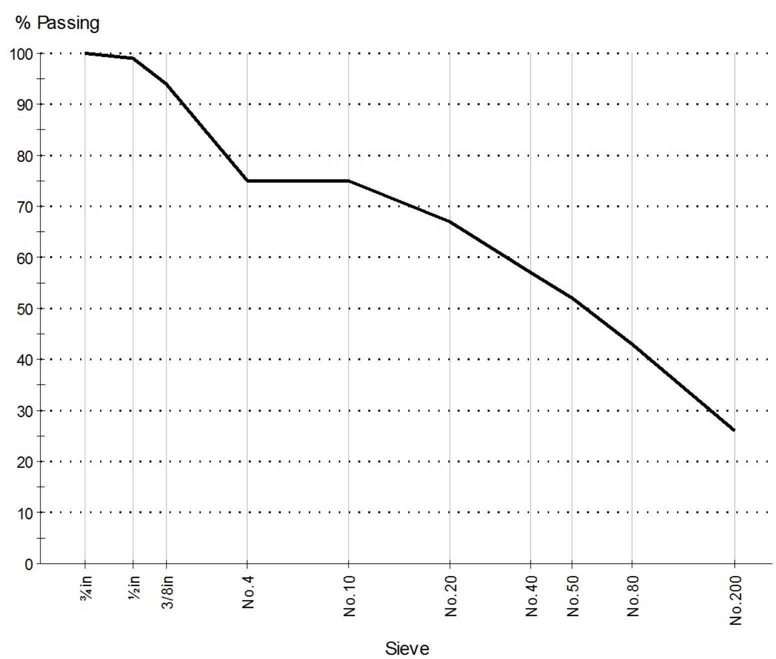
Project: BAY COLONY GROUP - LAB TESTING
CANTON, MA

Sample Details

Sample ID: 0446516-68-S1
Client Sample ID:
Date Sampled:
Sampled By: Others
Specification: No Spec. Sieve
Supplier:
Source:
Material:
Sampling Method:
General Location: Chestnut St. over Ipswich River - North Reading, MA
Location: Upstream Left Bank
Lift:

Sample Description:

Particle Size Distribution



COBBLES	GRAVEL		SAND			FINES (25.5%)	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
(0.0%)	(0.0%)	(24.7%)	(0.5%)	(17.5%)	(31.7%)		

Grading: ASTM C 136, ASTM C 117

Date Tested: 10/17/2022
Tested By: Gary Brooks

Sieve Size	% Passing	Limits
¾in (19.0mm)	100	
½in (12.5mm)	99	
3/8in (9.5mm)	94	
No.4 (4.75mm)	75	
No.10 (2.0mm)	75	
No.20 (850µm)	67	
No.40 (425µm)	57	
No.50 (300µm)	52	
No.80 (180µm)	43	
No.200 (75µm)	26	

D85: 6.8412 **D60:** 0.5232 **D50:** 0.2678
D30: 0.0922 **D15:** N/A **D10:** N/A

intertek psi

Professional Service Industries, Inc.
480 Neponset Street, Suite 9C
Canton, MA 02021

Phone: (781) 821-2355
Fax: (781) 821-6276

Report No: MAT:0446516-68-S2
Issue No: 1

Material Test Report

Client: BAY COLONY GROUP
4 SCHOOL ST., P.O. BOX 9136
FOXBORO, MA 02035

CC:

Project: BAY COLONY GROUP - LAB TESTING
CANTON, MA

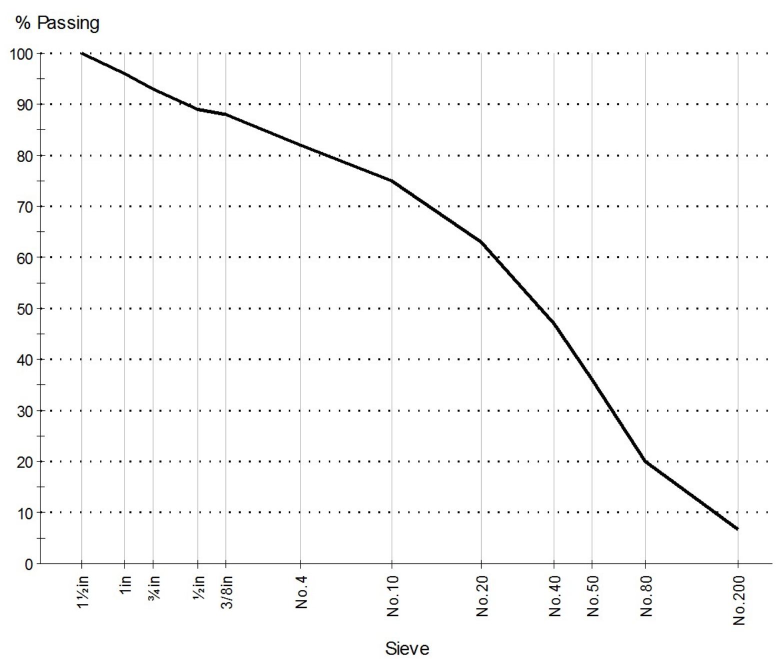
Approved Signatory: Yannick Lastennet (Department Manager)
Date of Issue: 10/20/2022

Sample Details

Sample ID:	0446516-68-S2
Client Sample ID:	
Date Sampled:	
Sampled By:	Others
Specification:	No Spec. Sieve
Supplier:	
Source:	
Material:	
Sampling Method:	
General Location:	Chestnut St. over Ipswich River - North Reading, MA
Location:	Upstream Right Bank
Lift:	

Sample Description:

Particle Size Distribution



COBBLES	GRAVEL		SAND			FINES (6.7%)	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
(0.0%)	(7.2%)	(11.2%)	(7.0%)	(27.7%)	(40.3%)		

Grading: ASTM C 136, ASTM C 117

Date Tested: 10/17/2022
Tested By: Gary Brooks

Sieve Size	% Passing	Limits
1½in (37.5mm)	100	
1in (25.0mm)	96	
¾in (19.0mm)	93	
½in (12.5mm)	89	
3/8in (9.5mm)	88	
No.4 (4.75mm)	82	
No.10 (2.0mm)	75	
No.20 (850µm)	63	
No.40 (425µm)	47	
No.50 (300µm)	36	
No.80 (180µm)	20	
No.200 (75µm)	6.7	

D85: 6.7175 **D60:** 0.7464 **D50:** 0.4840
D30: 0.2477 **D15:** 0.1295 **D10:** 0.0932
Cu: 8.01 **Cc:** 0.88

7.4.2 Scour Calculations

Project Name:	Ipswich River @ Chestnut Street, North Reading
Project Location:	Chestnut Street, North Reading
Project Job Number:	22-0171
Alternative:	48' Span

Determine Critical Velocity

$V_c = K_u y^{1/6} D^{1/3}$

V_c = Critical velocity above which bed material of D and smaller will be transported, ft/s

y = Average depth of flow upstream of the bridge, ft

D = Particle size for V_c, ft

D_{50} = Particle size in a mixture of which 50% are smaller, ft

K_u = 11.17

	Design Flood 4% Annual Probability	Check Flood 2% Annual Probability
	Data Input	Data Input
y =	8.4	8.8
D =	0.002265	0.002265
K_u =	11.17	11.17
Upstream Velocity (ft/sec)	1.1	1.1

Sta. 27590

Data Output		
V_c =	**2.1**	**2.1**

Determine Scour Conditions

	4% Annual Probability		2% Annual Probability	
	Left Abutment	Right Abutment	Left Abutment	Right Abutment
L, Length of Embankment (ft)	173	139	189	144
B_f, Width of Floodplain (ft)	173	139	189	144
L/B_f	1.00	1.00	1.00	1.00
Scour Condition	A	A	A	A

Condition A (Live Bed) - If $L/B_f \geq 0.75$ Scour occurs when the abutment is in or close to the channel

Condition B (Clear Water) - If $L/B_f < 0.75$ Scour occurs when the abutment is set back from the main channel

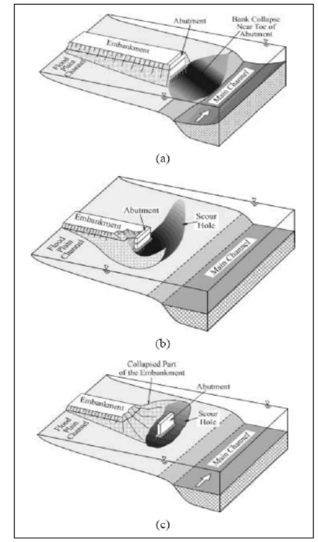


Figure 8.7. Abutment scour conditions (NCHRP 2010b).

Determine Set-back Ratio (SBR)

	4% Annual Probability		2% Annual Probability	
	Left Abutment	Right Abutment	Left Abutment	Right Abutment
Setback Length (ft)	0.0	0.0	0.0	0.0
Channel Flow Depth (ft)	7.3	7.3	7.6	7.6
SBR	0.0	0.0	0.0	0.0

NCHRP 24-20 Abutment Scour Approach

$y_c = y_1 (q_{2c}/q_1)^{6/7}$ **Live-Bed Abutment Scour**

$y_c = [q_{2c}/K_u D_{50}^{1/3}]^{6/7}$ **Clear-Water Abutment Scour**

Data Input

	Design Flood 4% Annual Probability	Check Flood 2% Annual Probability
Contraction Scour Calculation Method Used	Live-Bed	Live-Bed
D_{50} = Particle size in a mixture of which 50% are smaller, ft	0.002265	0.002265
y_1 = upstream flow depth, ft	8.4	8.8
v_1 = upstream velocity, ft/sec	1.1	1.1
W_1 = width upstream, ft	40.0	40.0
Q_1 = total discharge upstream, ft^3/sec	895	1,071
Q_2 = total discharge in the bridge opening, ft^3/sec	895	1,071
y_2 = flow depth in the contracted section, ft	7.3	7.6
v_2 = velocity in the contracted section, ft/sec	4.4	4.9
W_2 = width of bridge opening, ft	48.0	48.0
q_{2c} = unit discharge in the constricted opening accounting for non-uniform flow distribution, ft2/sec	18.6	22.3
q_1 = upstream unit discharge, ft^2/sec	22.4	26.8
q_{2c}/q_1 =	0.833	0.833
y_c = flow depth including live-bed or clear-water contraction scour, ft	7.2	7.5
α_A = amplification factor for live-bed conditions	1.20	1.20
α_B = amplification factor for clear-water conditions		
y_{max} = maximum flow depth resulting from abutment scour, ft	8.6	9.0
Y_0 = flow depth prior to scour, ft	7.3	7.6
Y_s = abutment scour depth, ft	**1.3**	**1.4**

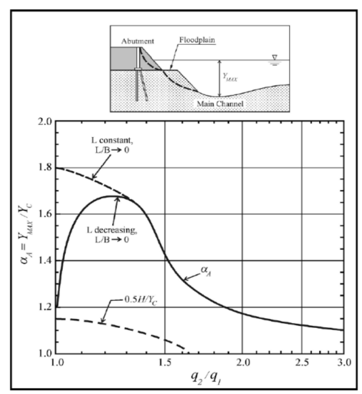


Figure 8.9. Scour amplification factor for spill-through abutments and live-bed conditions (NCHRP 2010b).

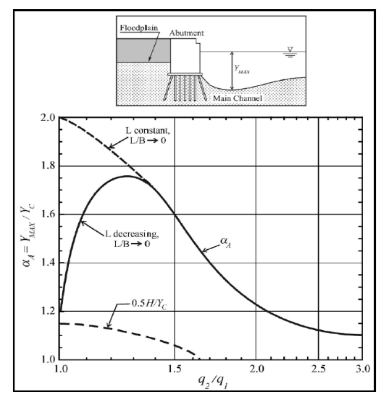


Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).

Project Name:	Ipswich River @ Chestnut Street, North Reading
Project Location:	Chestnut Street, North Reading
Project Job Number:	22-0171
Alternative:	34' Span

Determine Critical Velocity

$V_c = K_u\, y^{1/6}\, D^{1/3}$

V_c = Critical velocity above which bed material of D and smaller will be transported, ft/s

y = Average depth of flow upstream of the bridge, ft

D = Particle size for V_c, ft

D_{50} = Particle size in a mixture of which 50% are smaller, ft

K_u = 11.17

	Design Flood 4% Annual Probability	Check Flood 2% Annual Probability
	Data Input	Data Input
y =	6.5	7.0
D =	0.002265	0.002265
K_u =	11.17	11.17
Upstream Velocity (ft/sec)	1.7	1.6

Sta. 27303

Data Output		
V_c =	2.0	2.0

Determine Scour Conditions

	4% Annual Probability		2% Annual Probability	
	Left Abutment	Right Abutment	Left Abutment	Right Abutment
L, Length of Embankment (ft)	178	141	195	219
B_f, Width of Floodplain (ft)	178	141	195	219
L/B_f	1.00	1.00	1.00	1.00
Scour Condition	A	A	A	A

Condition A (Live Bed) - If $L/B_f \geq 0.75$ Scour occurs when the abutment is in or close to the channel

Condition B (Clear Water) - If $L/B_f < 0.75$ Scour occurs when the abutment is set back from the main channel

Determine Set-back Ratio (SBR)

	4% Annual Probability		2% Annual Probability	
	Left Abutment	Right Abutment	Left Abutment	Right Abutment
Setback Length (ft)	0.0	0.0	0.0	0.0
Channel Flow Depth (ft)	11.1	11.1	11.5	11.5
SBR	0.0	0.0	0.0	0.0

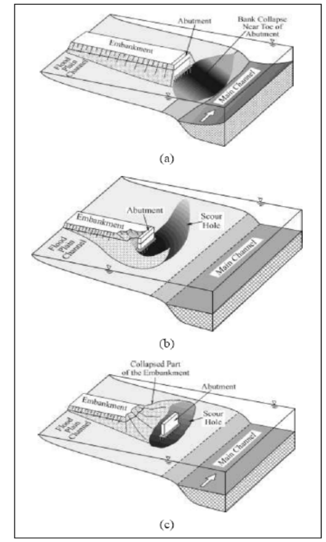


Figure 8.7. Abutment scour conditions (NCHRP 2010b).

NCHRP 24-20 Abutment Scour Approach

$y_c = y_1\,(q_{2c}/q_1)^{6/7}$ **Live-Bed Abutment Scour**

$y_c = [q_{2c}/K_u\, D_{50}^{1/3}]^{6/7}$ **Clear-Water Abutment Scour**

Data Input

	Design Flood 4% Annual Probability	Check Flood 2% Annual Probability
Contraction Scour Calculation Method Used	Live-Bed	Live-Bed
D_{50} = Particle size in a mixture of which 50% are smaller, ft	0.002265	0.002265
y_1 = upstream flow depth, ft	6.5	7.0
v_1 = upstream velocity, ft/sec	1.7	1.6
W_1 = width upstream, ft	44.0	44.0
Q_1 = total discharge upstream, ft^3/sec	895	1,071
Q_2 = total discharge in the bridge opening, ft^3/sec	895	1,071
y_2 = flow depth in the contracted section, ft	11.1	11.5
v_2 = velocity in the contracted section, ft/sec	3.9	4.3
W_2 = width of bridge opening, ft	34.0	34.0
q_{2c} = unit discharge in the constricted opening accounting for non-uniform flow distribution, ft2/sec	26.3	31.5
q_1 = upstream unit discharge, ft^2/sec	20.3	24.3
q_{2C}/q_1 =	1.294	1.294
y_c = flow depth including live-bed or clear-water contraction scour, ft	8.2	8.7
α_A = amplification factor for live-bed conditions	1.75	1.75
α_B = amplification factor for clear-water conditions		
y_{max} = maximum flow depth resulting from abutment scour, ft	14.3	15.3
Y_0 = flow depth prior to scour, ft	11.1	11.5
Y_s = abutment scour depth, ft	3.2	3.8

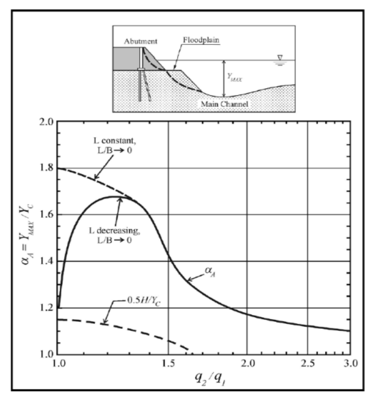


Figure 8.9. Scour amplification factor for spill-through abutments and live-bed conditions (NCHRP 2010b).

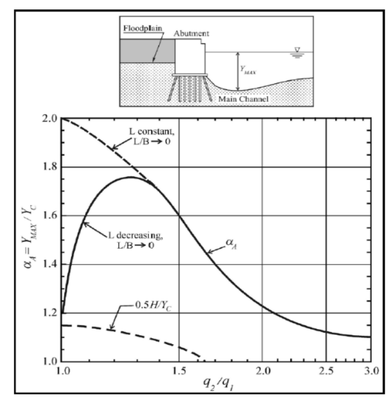


Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).

Project Name:	Ipswich River @ Chestnut Street North Reading
Project Location:	Chestnut Street North Reading, MA
Project Job Number:	22-0171
Frequency Event:	25-year (Alternative 1 - 48' Span)

Determine Critical Velocity

$V_c = K_u y^{1/6} D^{1/3}$

V_c = Critical velocity above which bed material of D and smaller will be transported, ft/s

y = Average depth of flow upstream of the bridge, ft

D = Particle size for V_c, ft

D_{50} = Particle size in a mixture of which 50% are smaller, ft

K_u = 11.17

Data Input

y =	11.0	ft
D =	0.002265	ft
K_u =	11.17	

Velocity Upstream of Bridge = 4.0 ft/sec

Data Output

V_c = **2.2** ft/sec

Critical Velocity V_C is less than mean velocity V therefore Live Bed conditions

Modified Laursen's 1960 Equation for Contraction Scour (Live Bed Condition)

$y2/y1 = (Q2/Q1)^{6/7} (W1/W2)^{k1}$

	Data Input
y_1 = Average depth in the upstream main channel, ft	11.0
y_2 = Average depth in the contracted section, ft	11.0
y_o = Existing depth in the contracted section before scour, ft	7.3
Q_1 = Flow in the upstream channel transporting sediment, ft3/s	895
Q_2 = Flow in the contracted channel, ft3/s	895
W_1 = Bottom width of the upstream main channel that is transporting bed material, ft	48
W_2 = Bottom width of main channel in contracted section less pier width, ft	48
k1 = Exponent determined in Section 6.3 HEC No. 18	0.69
$V^* = (g y_1 S_1)^{1/2}$, ft/sec	1.01
T = Fall velocity of bed material based on the D50, Figure 6.8 HEC No. 18 multiplied 3.28, ft/sec	0.09
g = acceleration of gravity, (32.2 ft/sec)	32.2
S_1 = Slope of energy grade line of main channel, ft/ft	0.003
τ = Shear stress on the bed, lb/ft^2	0.99
Δ = Density of water (1.94 slugs/ft^3)	1.94

Data Output

y_2 = **11.0** ft average depth from water surface

$y_s = y_2 - y_0$ = **3.7** ft average depth of scour

Project Name:	Ipswich River @ Chestnut Street North Reading
Project Location:	Chestnut Street North Reading, MA
Project Job Number:	22-0171
Frequency Event:	50-year (Alternative 1 - 48' Span)

Determine Critical Velocity

$V_c = K_u y^{1/6} D^{1/3}$

V_c = Critical velocity above which bed material of D and smaller will be transported, ft/s

y = Average depth of flow upstream of the bridge, ft

D = Particle size for V_c, ft

D_{50} = Particle size in a mixture of which 50% are smaller, ft

K_u = 11.17

Data Input

y =	11.4	ft
D =	0.002265	ft
K_u =	11.17	

Velocity Upstream of Bridge = 4.4 ft/sec

Data Output

V_c = **2.2** ft/sec

Critical Velocity V_C is less than mean velocity V therefore Live Bed conditions

Modified Laursen's 1960 Equation for Contraction Scour (Live Bed Condition)

$y2/y1 = (Q2/Q1)^{6/7} (W1/W2)^{k1}$

	Data Input
y_1 = Average depth in the upstream main channel, ft	11.4
y_2 = Average depth in the contracted section, ft	11.4
y_o = Existing depth in the contracted section before scour, ft	7.6
Q_1 = Flow in the upstream channel transporting sediment, ft3/s	1071
Q_2 = Flow in the contracted channel, ft3/s	1071
W_1 = Bottom width of the upstream main channel that is transporting bed material, ft	48
W_2 = Bottom width of main channel in contracted section less pier width, ft	48
k1 = Exponent determined in Section 6.3 HEC No. 18	0.69
$V^* = (gy_1S_1)^{1/2}$, ft/sec	1.11
T = Fall velocity of bed material based on the D50, Figure 6.8 HEC No. 18 multiplied 3.28, ft/sec	0.09
g = acceleration of gravity, (32.2 ft/sec)	32.2
S_1 = Slope of energy grade line of main channel, ft/ft	0.003
τ = Shear stress on the bed, lb/ft^2	0.99
Δ = Density of water (1.94 slugs/ft^3)	1.94

Data Output

y_2 = **11.4** ft average depth from water surface

$y_s = y_2 - y_0$ = **3.8** ft average depth of scour

Project Name:	Ipswich River @ Chestnut Street North Reading
Project Location:	Chestnut Street North Reading, MA
Project Job Number:	22-0171
Frequency Event:	25-year (Alternative 2 - 34' Span)

Determine Critical Velocity

$V_c = K_u y^{1/6} D^{1/3}$

V_c = Critical velocity above which bed material of D and smaller will be transported, ft/s

y = Average depth of flow upstream of the bridge, ft

D = Particle size for V_c, ft

D_{50} = Particle size in a mixture of which 50% are smaller, ft

K_u = 11.17

Data Input

y =	11.1	ft
D =	0.002265	ft
K_u =	11.17	

Velocity Upstream of Bridge = 3.9 ft/sec

Data Output

V_c = **2.2** ft/sec

Critical Velocity V_C is less than mean velocity V therefore Live Bed conditions

Modified Laursen's 1960 Equation for Contraction Scour (Live Bed Condition)

$y2/y1 = (Q2/Q1)^{6/7} (W1/W2)^{k1}$

	Data Input
y_1 = Average depth in the upstream main channel, ft	11.1
y_2 = Average depth in the contracted section, ft	11.1
y_o = Existing depth in the contracted section before scour, ft	7.5
Q_1 = Flow in the upstream channel transporting sediment, ft3/s	895
Q_2 = Flow in the contracted channel, ft3/s	895
W_1 = Bottom width of the upstream main channel that is transporting bed material, ft	34
W_2 = Bottom width of main channel in contracted section less pier width, ft	34
k1 = Exponent determined in Section 6.3 HEC No. 18	0.69
$V^* = (gy_1S_1)^{1/2}$, ft/sec	0.98
T = Fall velocity of bed material based on the D50, Figure 6.8 HEC No. 18 multiplied 3.28, ft/sec	0.09
g = acceleration of gravity, (32.2 ft/sec)	32.2
S_1 = Slope of energy grade line of main channel, ft/ft	0.003
τ = Shear stress on the bed, lb/ft^2	0.99
Δ = Density of water (1.94 slugs/ft^3)	1.94

Data Output

y_2 = **11.1** ft average depth from water surface

$y_s = y_2 - y_0$ = **3.6** ft average depth of scour

Project Name:	Ipswich River @ Chestnut Street North Reading
Project Location:	Chestnut Street North Reading, MA
Project Job Number:	22-0171
Frequency Event:	50-year (Alternative 2 - 34' Span)

Determine Critical Velocity

$V_c = K_u y^{1/6} D^{1/3}$

V_c = Critical velocity above which bed material of D and smaller will be transported, ft/s

y = Average depth of flow upstream of the bridge, ft

D = Particle size for V_c, ft

D_{50} = Particle size in a mixture of which 50% are smaller, ft

K_u = 11.17

Data Input

y =	11.8	ft
D =	0.002265	ft
K_u =	11.17	

Velocity Upstream of Bridge = 4.3 ft/sec

Data Output

V_c = **2.2** ft/sec

Critical Velocity V_C is less than mean velocity V therefore Live Bed conditions

Modified Laursen's 1960 Equation for Contraction Scour (Live Bed Condition)

$y2/y1 = (Q2/Q1)^{6/7} (W1/W2)^{k1}$

	Data Input
y_1 = Average depth in the upstream main channel, ft	11.8
y_2 = Average depth in the contracted section, ft	11.8
y_o = Existing depth in the contracted section before scour, ft	7.9
Q_1 = Flow in the upstream channel transporting sediment, ft3/s	1071
Q_2 = Flow in the contracted channel, ft3/s	1071
W_1 = Bottom width of the upstream main channel that is transporting bed material, ft	34
W_2 = Bottom width of main channel in contracted section less pier width, ft	34
k1 = Exponent determined in Section 6.3 HEC No. 18	0.69
$V^* = (gy_1S_1)^{1/2}$, ft/sec	1.01
T = Fall velocity of bed material based on the D50, Figure 6.8 HEC No. 18 multiplied 3.28, ft/sec	0.02
g = acceleration of gravity, (32.2 ft/sec)	32.2
S_1 = Slope of energy grade line of main channel, ft/ft	0.003
τ = Shear stress on the bed, lb/ft^2	0.99
Δ = Density of water (1.94 slugs/ft^3)	1.94

Data Output

y_2 = **11.8** ft average depth from water surface

$y_s = y_2 - y_0$ = **3.8** ft average depth of scour

Bay Colony Group, Inc.
Professional Civil Engineers & Land Surveyors

Four School Street
P.O. Box 9136
Foxborough, MA 02035
(508)543-3939
(508)543-8866 fax

E-Mail:mailbox@baycolonygroup.com *** http://www.baycolonygroup.com

MEMORANDUM

October 18, 2023

To: Robert Niccoli, P.E., S.E., Director of Structures

From: William Buckley, Jr., P.E., Project Manager

Subject: North Reading: Bridge No. N18003-2D4-MUN-NBI, Chestnut Street over Ipswich River Cofferdam Elevation, Project 22-0171

Transmitted herewith is the memorandum for the cofferdam elevation for the subject bridge. If you have questions regarding this document please contact William Buckley, Jr., 508.543.3939 x214 or billbuckley@baycolonygroup.com.

A steady-state analysis was conducted using the USACE HEC-RAS program for the 2-year return event in accordance with the standards outlined in the MassDOT LRFD Bridge Manual Part 1.3.3.4.E (January, 2020). In accordance with the LRFD Manual, the design flood event for temporary construction of less than one year is the 2-year flood frequency event that was computed using the USGS PeakFQ flow and simple drainage area ratio methods as outlined in the Hydraulic Study Report dated November 18, 2022.

The water surface profile for the existing condition was evaluated assuming that one culvert would be closed, and the other culvert would remain in operation. Table 1 shows the predicted water surface elevation during construction.

Flood Frequency	Peak Flow (cfs)	Water Surface Elevation (ft)	Velocity (ft/sec)	Recommended Elevation for Cofferdam (ft)
2-year	403	67.7	5.2	68.7

Recommendation – The recommended elevation of the top of the cofferdam is 68.7’ if the temporary construction is less than one year.