Hydraulic Report

Bruce Freeman Rail Trail
over Pantry Brook
Sudbury, Massachusetts

September 26, 2019

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1.0 Introduction

1.1 Purpose

The purpose of this report is to evaluate the hydraulic performance and scour safety for the existing bridge and proposed bridge replacement for Bruce Freeman Rail Trail over Pantry Brook. This investigation was conducted in accordance with the Federal Highway Administration (FHWA) and Massachusetts Department of Transportation (MassDOT) LRFD Bridge Manual for performing hydraulic studies at bridges.

1.2 Executive Summary

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

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

A hydrologic analysis was completed to estimate peak flow rates for various storm return frequencies. The contributing watershed area was measured to be approximately 2.5 square miles. The Hydraulic Design Return Frequency for a rail trail is the 10-year event. The estimated peak discharge flow rates for the 10-year and 100-year flood return frequencies are 204 cfs and 476 cfs, respectively.

The hydraulic analysis indicates that the proposed bridge structure does not change flood levels during the 100-Year base flood.

The scour safety analysis includes estimated depths for contraction scour and local abutment scour at both abutments. The scour design return flood frequency is the 25-year event, and the scour check return flood frequency is the 50-year event. The estimated total scour depths are 1.15 feet and 1.29 feet, respectively.

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

2.0 Project Description

2.1 Existing Structure

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

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

2.2 Crossed Waterway

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

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

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

2.3 Highway Conveyed

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

2.4 Land Uses in Vicinity of Bridge

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

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

2.5 Special Site Considerations

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

3.0 Data Collection

3.1 Data Sources

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

- NOAA Atlas 14 Point Precipitation Frequency Estimates published by the Hydrometeorological Design Studies Center (available online at https://hdsc.nws.noaa.gov/hdsc/pfds/).
- MassDOT Load and Resistance Factor Design (LRFD) Bridge Manual, 2009, Updated December 2013.
- Maynard, USGS Topographic Map, Scale 1:24,000.
- National Flood Insurance Program (NFIP), Flood Insurance Rate Map (FIRM), Town of Sudbury, MA, Panel 366 of 656 (Map Number: 25017C0366F), July 7, 2014.
- National Flood Insurance Program (NFIP), Flood Insurance Rate Map (FIRM), Town of Sudbury, MA, Panel 368 of 656 (Map Number: 25017C0368F), July 7, 2014.
- Flood Insurance Study (FIS), Middlesex County, MA, Volume 1 (FIS Number: 25017CV001C), Revised: July 6, 2016.
- Flood Insurance Study (FIS), Middlesex County, MA, Volume 2 (FIS Number: 25017CV002C), Revised: July 6, 2016.
- Flood Insurance Study (FIS), Middlesex County, MA, Volume 6 (FIS Number: 25017CV006C), Revised: July 6, 2016.
- Geotechnical Particle Size Distribution Report, Boring BB-101, Sample S9, Thielsch Engineering, Inc., September 16, 2019.
- Geotechnical Particle Size Distribution Report, Boring BB-102A, Sample S9, Thielsch Engineering, Inc., September 16, 2019.
- Federal Highway Administration (FHWA), Hydraulic Engineering Circular Number 18, *HEC-18 Evaluating Scour at Bridges*, April 2012.
- Federal Highway Administration (FHWA), Hydraulic Engineering Circular Number 23, *HEC-23 Bridge Scour and Stream Instability Countermeasures*, March 2001.

3.2 Data Application

An explanation of how key references and data sources are used in this study is described below:

- Data from the Atlas 14 Precipitation Frequency Estimates were utilized in the hydrologic analysis to determine peak flows at the project location.
- The MassDOT LRFD Bridge Manual provided design criteria and recommendations for the hydrologic, hydraulic, and scour analyses.
- The USGS topographic maps were utilized for completing the hydrologic analysis.
- The NFIP FIRM was used to determine if the project location is within a regulatory floodplain and what information may be available for the hydraulic analysis.
- The FIS was used to obtain information consisting of the regulatory base flood elevation and water surface profile for calibrating the HEC-RAS existing conditions model.
- HEC-18 was used for the scour analysis.
- The geotechnical soil gradations were used in the scour analysis to determine depth of contraction scour.
- HEC-23 was used to determine riprap protection.

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

4.0 Engineering Methods

4.1 Hydrologic Analysis

The watershed area for the project location was delineated and characterized using surveyed contour and topographic information located in the vicinity of the project limits and supplemented with USGS topography for areas extending beyond the survey limits. Due to Mineway Brook entering Pantry Book near the bridge location, it was necessary to delineate these waterways as separate watersheds for the hydraulic analysis. Ground cover and land use characteristics were identified using the survey from the project and supplemented with aerial imagery. Refer to Appendix 6.2 for a watershed map and USGS maps for the watershed area.

Soil types within the watershed were determined using soil map data obtained from the National Resources Conservation Service (NRCS). Soils within the watershed area for the project primarily consist of HSG C.

The time of concentration for this drainage area was determined by the velocity method, which is the summation of travel times for segments along the hydraulically most distant flow path consisting of sheet flow, shallow concentration flow, and open channel flow. To quantify offsite contributing flows, educated assumptions were made for area sizes, land usage/character, and watercourse locations.

Rainfall data for the project area was obtained from the NOAA Atlas 14 Point Precipitation Frequency Estimates and was applied to the Type III rainfall distribution curve for each storm event. Refer to Appendix 6.1 for detailed rainfall data.

Peak flows for the 10, 25, 50, 100, and 500-year return frequency were calculated using the HydroCAD Stormwater Modeling software (Version 9.0), based on the TR-20 methodology. By overlaying GIS soil maps from the NRCS on aerial imagery of the existing ground cover and topographic information, a composite curve number was calculated for the drainage area. The table below summarizes the rainfall amounts and estimated peak flow rates for the various flood return frequencies at the bridge location. Appendix 6.3 contains the HydroCAD hydrologic results.

Summary of Rainfall Amounts and Estimated Peak Discharge Flow Rates

Flood Return Frequency	Type III 24-hr Rainfall Amount (in.)	*Peak Discharge Flow Rate (cfs)
10-year	5.06	204
25-year	6.19	305
50-year	7.03	385
100-year	7.94	476
500-year	10.80	783

**Peak Discharge Flow Rate is at bridge location.*

Flow data for Pantry Brook and Mineway Brook were obtained from the FEMA FIS, and the 100-year flow for these two streams at their confluence with each other is 150 cfs and 190 cfs, respectively. These two flows combine to equal 340 cfs, which provides an estimated flow rate for Pantry Brook at the project location. The FEMA flow rate was not used for the hydraulic analyses due to changes in land use and the publication of updated and more intense rainfall data since the FIS was completed.

4.2 Hydraulic Analysis

The existing bridge location is within a delineated NFIP regulatory floodway. Therefore, it is necessary to perform a "No Rise" base flood elevation profile in accordance with Section 1.3.5 of the MassDOT Bridge Manual. The hydraulic design flood return frequency for this bridge is a 10-year event. Both the existing and proposed bridge hydraulics were evaluated for the 10, 25, 50, 100, and 500-year design flood return frequencies.

A steady flow analysis of the existing conditions for the Bruce Freeman Rail Trail Bridge was developed using the U.S. Army Corps of Engineers (USACOE), Hydrologic Engineering Center River Analysis System (HEC-RAS) program, Version 5.0.6. The NFIP FIRM flood map for Panty Brook shows the project location within the delineated "Zone AE" boundary, which indicates that base flood elevations have been determined for this waterway. Available files for Pantry Brook were obtained from FEMA; however, at the project location the files only contained PDF information from the HEC-2 modeling software and did not include any input files for use with HEC-RAS.

Consequently, a new hydraulic model of the existing conditions was assembled and calibrated based on the known base flood elevation and water surface profile. FEMA Cross Section "C" was used for calibration of the existing model and is located approximately 400' upstream of the bridge location. The FIRM maps and FIS floodway data and flood profile are included in Appendix 6.4.

A total of 19 cross-sections, 1 bridge, and 3 reaches with one junction were modeled in both the existing conditions and proposed conditions HEC-RAS model. The limits of the model are approximately 500 feet upstream and approximately 500 feet downstream of the bridge on Pantry Brook. Mineway Book enters Pantry Brook near the bridge location and has a limit in the model extending approximately 500 feet upstream from the confluence with Pantry Brook.

The channel and surrounding floodplain geometry were obtained from topographic survey data for the site. The topographic survey was performed in Spring 2019.

Manning's "n" values were initially determined by site photographs and aerial photographs to reflect the roughness of the channel and overbanks; however, these values were adjusted as part of the calibration process of the base flood profile for existing conditions model. The contraction and expansion coefficients were held constant at 0.1 and 0.3 values, respectively at open-stream cross sections.

A proposed conditions model was then created by duplicating the calibrated existing hydraulic model and modifying the bridge information to reflect the proposed bridge structure geometry. The proposed bridge consists of a 34-foot clear span with riprap placed on the inside the structure between the existing abutments and proposed foundations. Placement of the stone fill reduces the hydraulic opening to a width of approximately 25'-6" and accommodates the 1.2 times the bank full width measurement. The structure rise from the stream bed to low bottom chord is 7'-2" foot rise.

A summary of the hydraulic performance for existing and proposed conditions for the various design flood return frequencies is presented in the table below. The HEC-RAS hydraulic model and results for the existing and proposed conditions are included in Appendix 6.5 and Appendix 6.6.

Summary of Hydraulic Performance

HEC-RAS Model Description	Return Period (Year)	Flow (cfs)	*Water Surface Elev., 400'+/- Upstream (ft)	Channel Velocity, Inside Bridge (ft/s)
Existing Conditions	10	204	122.12	5.19
	25	305	122.81	6.67
	50	385	123.31	7.67
	100	476	123.88	8.69
	500	783	125.56	11.80
Proposed Conditions	10	204	122.12	3.27
	25	305	122.81	3.96
	50	385	123.31	4.43
	100	476	123.88	4.91
	500	783	125.56	6.46

** Water surface elevation at HEC-RAS River Station 882.*

4.3 Scour / Stability Analysis

The goal of the scour analysis is to evaluate the potential for long-term degradation, determine the contraction scour depth for the proposed bridge abutment foundations, and determine the local scour depth at the proposed abutments. The total potential scour for a bridge is estimated as the sum of these three components: long-term aggradation or degradation trends, contraction scour, and local scour (such as abutments and piers).

Two soil borings were taken in the vicinity of the bridge. The samples predominantly contained silty sands or sand with silt at a depth of 16-18 feet below the abandoned railroad surface. A particle grain size analysis was performed for both samples to determine the streambed D_{50} particle size. The smaller particle size was utilized in the scour calculations. The results are included in Appendix 6.7.

Scour was evaluated for the design flood return frequencies in accordance with Table 1.3.4-1 of the MassDOT Bridge Manual. The Scour Design Flood Return Frequency is 25 years, and the Scour Check Flood Return Frequency is 50 years. Both the Scour Design and Scour Check Flood Return Frequencies were used for calculating contraction scour and local abutment scour.

4.3.1 Long-Term Degradation

Long-term changes to a stream refer to trends in the geomorphic shape of the channel that are a result of evolutionary processes in the river basin and thought to occur over a period of years or decades rather than days. Long-term trends in channel aggradation and degradation and lateral migration should be predicted qualitatively based on available sources of information including mapping, field observations, history of flooding and erosion, previous inspection reports, geomorphology, soil characteristics, land uses, flow patterns, control works, and any other factors, which may have an influence on the river. If the trend is determined to be significant, several approaches ranging from sediment transport modeling to extrapolation and applying engineering judgment can be used to estimate stream bed changes and their effect on the bridge.

A review of historic aerial photographs and USGS topographic maps did not reveal any significant changes to the channel geometry. Therefore, the location of the channel has remained relatively stable. Recent photographs and topographic survey at the bridge show evidence of stream bed erosion along the north abutment.

Considering that the channel has remained stable over the service life of the existing bridge, it is assumed that the Long-term vertical scour trends for the proposed bridge will be negligible.

4.3.2 Contraction Scour

Contraction scour is the result of channel and floodplain width constrictions caused by the bridge crossing and approach embankments. Contraction scour occurs when the area of flow is decreased, resulting in increased velocities and bed shear stress in the contracted area. Contraction scour was calculated in accordance with HEC-18.

The scour analysis indicated that live-bed contraction scour occurs in the main channel through the bridge opening. The HEC-RAS model was used to obtain flow depths, channel velocities, and other metrics at the bridge and upstream of the bridge. The 25-year and 50-year design flood event contraction scour depths calculated through the proposed bridge are approximately 0.14 feet and 0.0 feet, respectively.

4.3.3 Local Abutment Scour

Local scour is the result of water flowing around an obstruction, such as a pier or an abutment. Obstructions induce the formation of vortex systems caused by the acceleration of flow around the object. These vortices remove stream bed material from the base of the obstruction while the intensity of the vortices diminishes downstream of the obstruction. The "MassDOT Modified Froehlich Equation" presented in Subsection 1.3.6 of the MassDOT Bridge Manual was used to estimate local abutment scour.

The HEC-RAS model was used to obtain the flow depths and velocities upstream of the abutments. The proposed structure consists of a spill through abutment configuration with wingwalls. Local abutment scour was calculated for both abutments of the bridge. The maximum calculated 25-year and 50-year scour depths for the proposed bridge occurred at the north abutment and are approximately 1.15 and 1.29, respectively.

4.3.4 Calculated Scour Summary

The scour analysis calculations are included in Appendix 6.7. A summary of the various scour depths and total scour depth is included below. The total scour is the sum of contraction scour and the deepest local abutment scour.

Summary of Calculated Scour Depths

Alternative	Return Period (Year)	Flow (cfs)	Contraction Scour (Feet)	Local South Abutment Scour (Feet)	Local North Abutment Scour (Feet)	Total Scour (Feet)
Existing Conditions (Single 12' span)	25	305	1.65	2.11	2.01	3.76
	50	385	1.91	2.39	2.56	4.47
Proposed Conditions (Single 34' span)	25	305	0.14	0.92	1.01	1.15
	50	385	0.00	1.04	1.29	1.29

4.4 Riprap Protection for Scour

To protect against potential scour problems at the proposed bridge abutments, countermeasures are required. The scour countermeasure for the proposed bridge includes riprap protection and with a size and depth estimated using HEC-23. Stream velocities and depths were obtained from the HEC-RAS analysis. The estimated D50 stone size is 3.9 inches, with a minimum layer thickness of 7.8 inches. The riprap calculations are included in Appendix 6.8.

5.0 Conclusions and Recommendations

5.1 Conclusions

The hydraulic model indicates that both the existing bridge and proposed bridge replacement type safely convey the 10-year design flood event.

The analysis also indicates that the proposed bridge will not result in any changes to the base flood elevation, complying with the “No Rise” Floodway Encroachment requirement.

5.2 Recommendations

The new slopes between the remaining existing stream bed and new foundations should be stabilized with Dumped Riprap (MassDOT Standard Specification M2.02.2) over a layer of crushed stone (MassDOT Standard Specification M2.02.1) placed on geotextile fabric for separation (MassDOT Standard Specification M9.50.0).

The total scour design and scour check depths estimated for the proposed conditions shall be utilized for the foundation bearing capacity and structural stability verification calculations.

5.3 Project Information Summary

Hydraulic Design Data:

Drainage Area	2.5 Square Miles
Design Flood Frequency	10-Years
Design Flood Discharge	204 cubic feet per second
Design Flood Velocity	3.27 feet per second
Design Flood Elevation	122.12 feet (NAVD 88)

Base (100-Year) Flood Data:

Discharge	476 cubic feet per second
Water Surface Elevation	123.80 feet (NAVD 88)

Design and Check Scour Data:

Design Scour Return Frequency	25 Years
Check Scour Return Frequency	50 Years

Flood of Record:

Return Frequency	Unknown
Peak Flow	Unknown
Bridge Outlet Velocity	Unknown
Water Surface Elevation	Unknown

APPENDIX 6.1:

NOAA ATLAS 14 PRECIPITATION DATA

NOAA Atlas 14, Volume 10, Version 3
Location name: Sudbury, Massachusetts, USA*
Latitude: 42.4053°, Longitude: -71.4041°
Elevation: 127.2 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sandra Pavlovic, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Orlan Wilhite

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.317 (0.241-0.406)	0.385 (0.292-0.494)	0.496 (0.376-0.639)	0.588 (0.443-0.762)	0.715 (0.525-0.970)	0.810 (0.586-1.12)	0.911 (0.644-1.32)	1.03 (0.689-1.51)	1.21 (0.780-1.83)	1.36 (0.859-2.10)
10-min	0.449 (0.341-0.576)	0.545 (0.414-0.700)	0.702 (0.532-0.904)	0.833 (0.628-1.08)	1.01 (0.744-1.38)	1.15 (0.828-1.59)	1.29 (0.912-1.86)	1.46 (0.975-2.14)	1.71 (1.11-2.59)	1.92 (1.22-2.97)
15-min	0.528 (0.402-0.677)	0.641 (0.487-0.823)	0.826 (0.625-1.06)	0.980 (0.739-1.27)	1.19 (0.876-1.62)	1.35 (0.975-1.87)	1.52 (1.07-2.19)	1.72 (1.15-2.52)	2.01 (1.30-3.05)	2.26 (1.43-3.50)
30-min	0.719 (0.547-0.922)	0.874 (0.664-1.12)	1.13 (0.854-1.45)	1.34 (1.01-1.73)	1.63 (1.20-2.21)	1.84 (1.33-2.56)	2.07 (1.47-2.99)	2.35 (1.57-3.44)	2.75 (1.78-4.17)	3.09 (1.96-4.78)
60-min	0.910 (0.692-1.17)	1.11 (0.841-1.42)	1.43 (1.08-1.84)	1.70 (1.28-2.19)	2.06 (1.52-2.80)	2.34 (1.69-3.24)	2.63 (1.86-3.80)	2.98 (1.99-4.36)	3.49 (2.25-5.29)	3.92 (2.48-6.06)
2-hr	1.17 (0.895-1.48)	1.43 (1.10-1.82)	1.85 (1.42-2.37)	2.21 (1.68-2.83)	2.70 (2.00-3.64)	3.06 (2.23-4.22)	3.45 (2.47-4.97)	3.93 (2.64-5.71)	4.68 (3.03-7.03)	5.32 (3.38-8.14)
3-hr	1.35 (1.04-1.71)	1.66 (1.28-2.09)	2.15 (1.66-2.73)	2.57 (1.96-3.28)	3.14 (2.34-4.21)	3.56 (2.61-4.89)	4.02 (2.89-5.77)	4.59 (3.09-6.63)	5.48 (3.56-8.19)	6.26 (3.98-9.52)
6-hr	1.74 (1.36-2.18)	2.13 (1.66-2.67)	2.77 (2.15-3.48)	3.29 (2.54-4.16)	4.02 (3.02-5.34)	4.56 (3.37-6.20)	5.14 (3.72-7.31)	5.87 (3.97-8.39)	7.01 (4.57-10.4)	8.01 (5.11-12.0)
12-hr	2.21 (1.74-2.74)	2.70 (2.12-3.35)	3.50 (2.74-4.35)	4.15 (3.23-5.20)	5.06 (3.83-6.65)	5.73 (4.26-7.71)	6.46 (4.69-9.06)	7.35 (5.00-10.4)	8.73 (5.71-12.8)	9.92 (6.35-14.8)
24-hr	2.65 (2.10-3.25)	3.25 (2.58-4.00)	4.24 (3.35-5.23)	5.06 (3.98-6.27)	6.19 (4.73-8.06)	7.03 (5.26-9.36)	7.94 (5.81-11.0)	9.06 (6.18-12.7)	10.8 (7.09-15.6)	12.3 (7.89-18.1)
2-day	2.98 (2.39-3.62)	3.72 (2.98-4.53)	4.93 (3.93-6.02)	5.93 (4.70-7.28)	7.31 (5.63-9.45)	8.32 (6.30-11.0)	9.44 (6.98-13.1)	10.9 (7.44-15.0)	13.1 (8.63-18.8)	15.1 (9.70-22.0)
3-day	3.25 (2.62-3.93)	4.04 (3.25-4.89)	5.34 (4.28-6.48)	6.42 (5.12-7.83)	7.90 (6.12-10.1)	8.98 (6.83-11.8)	10.2 (7.56-14.0)	11.7 (8.05-16.1)	14.2 (9.34-20.1)	16.3 (10.5-23.6)
4-day	3.51 (2.84-4.22)	4.33 (3.50-5.21)	5.67 (4.56-6.85)	6.78 (5.42-8.24)	8.31 (6.45-10.6)	9.43 (7.19-12.4)	10.7 (7.94-14.6)	12.2 (8.44-16.8)	14.8 (9.76-20.9)	17.0 (11.0-24.5)
7-day	4.24 (3.46-5.06)	5.09 (4.14-6.08)	6.49 (5.26-7.77)	7.64 (6.16-9.21)	9.24 (7.22-11.7)	10.4 (7.97-13.5)	11.7 (8.72-15.8)	13.3 (9.21-18.1)	15.9 (10.5-22.3)	18.1 (11.7-25.9)
10-day	4.92 (4.03-5.84)	5.80 (4.74-6.89)	7.23 (5.89-8.62)	8.41 (6.81-10.1)	10.0 (7.88-12.6)	11.3 (8.64-14.5)	12.6 (9.37-16.8)	14.2 (9.85-19.2)	16.7 (11.1-23.3)	18.8 (12.2-26.8)
20-day	6.91 (5.71-8.12)	7.85 (6.49-9.24)	9.40 (7.74-11.1)	10.7 (8.74-12.7)	12.5 (9.81-15.4)	13.8 (10.6-17.4)	15.2 (11.3-19.8)	16.7 (11.7-22.3)	19.0 (12.7-26.1)	20.8 (13.5-29.2)
30-day	8.55 (7.11-9.99)	9.56 (7.94-11.2)	11.2 (9.27-13.1)	12.6 (10.3-14.8)	14.4 (11.4-17.6)	15.9 (12.2-19.8)	17.3 (12.8-22.2)	18.8 (13.2-24.9)	20.9 (14.0-28.5)	22.4 (14.6-31.3)
45-day	10.6 (8.88-12.3)	11.7 (9.76-13.6)	13.4 (11.2-15.7)	14.9 (12.3-17.5)	16.9 (13.4-20.5)	18.5 (14.3-22.7)	20.0 (14.8-25.3)	21.5 (15.1-28.2)	23.3 (15.7-31.7)	24.6 (16.1-34.2)
60-day	12.3 (10.4-14.3)	13.5 (11.3-15.6)	15.3 (12.8-17.8)	16.9 (14.0-19.7)	19.0 (15.1-22.8)	20.6 (16.0-25.2)	22.2 (16.4-27.9)	23.7 (16.7-30.9)	25.4 (17.2-34.4)	26.6 (17.4-36.8)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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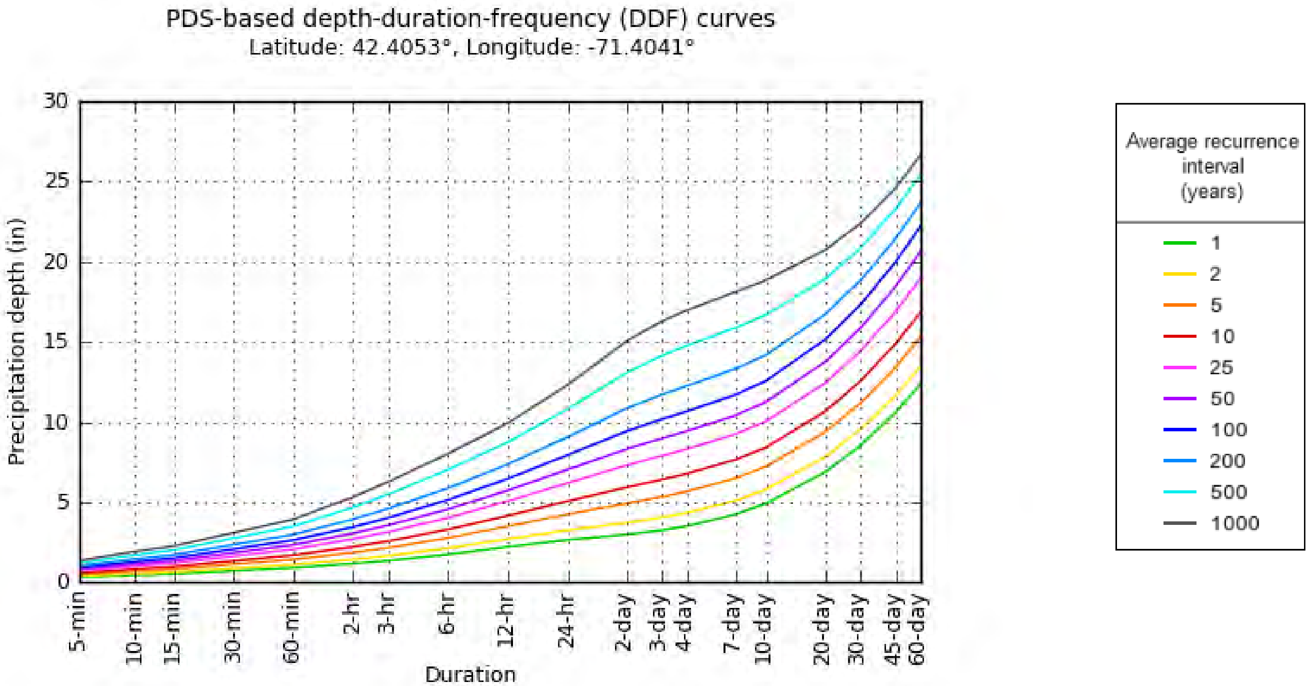
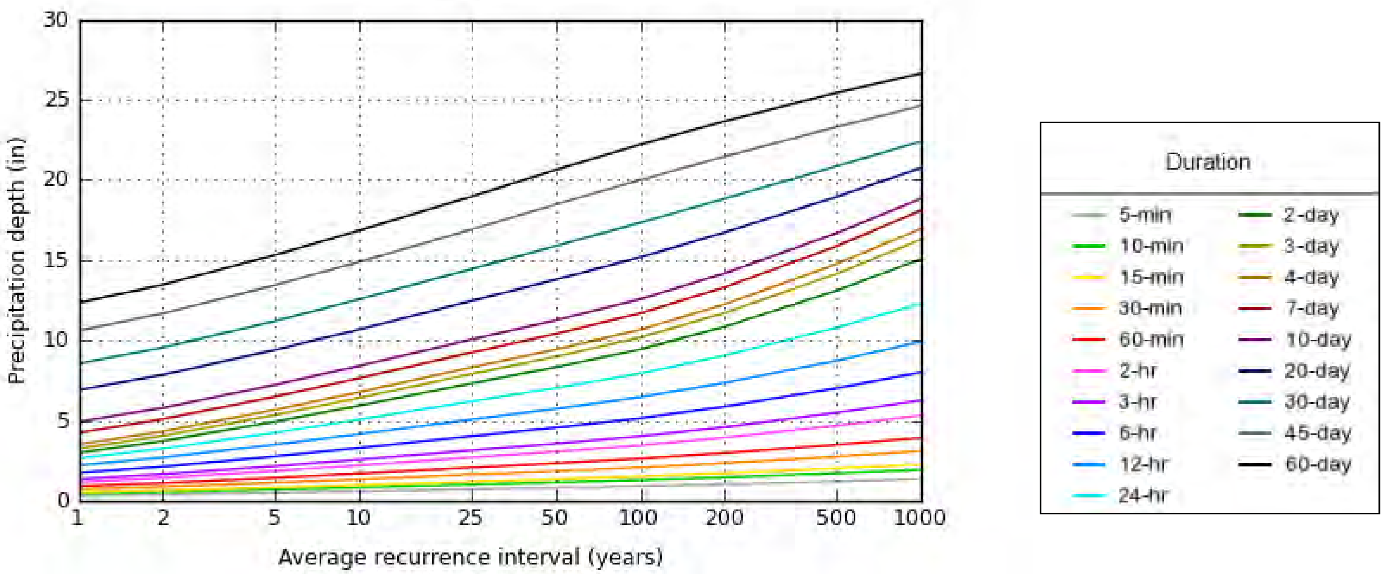
PF graphical





NOAA Atlas 14, Volume 10, Version 3

Created (GMT): Thu Sep 12 17:00:48 2019

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Maps & aerials

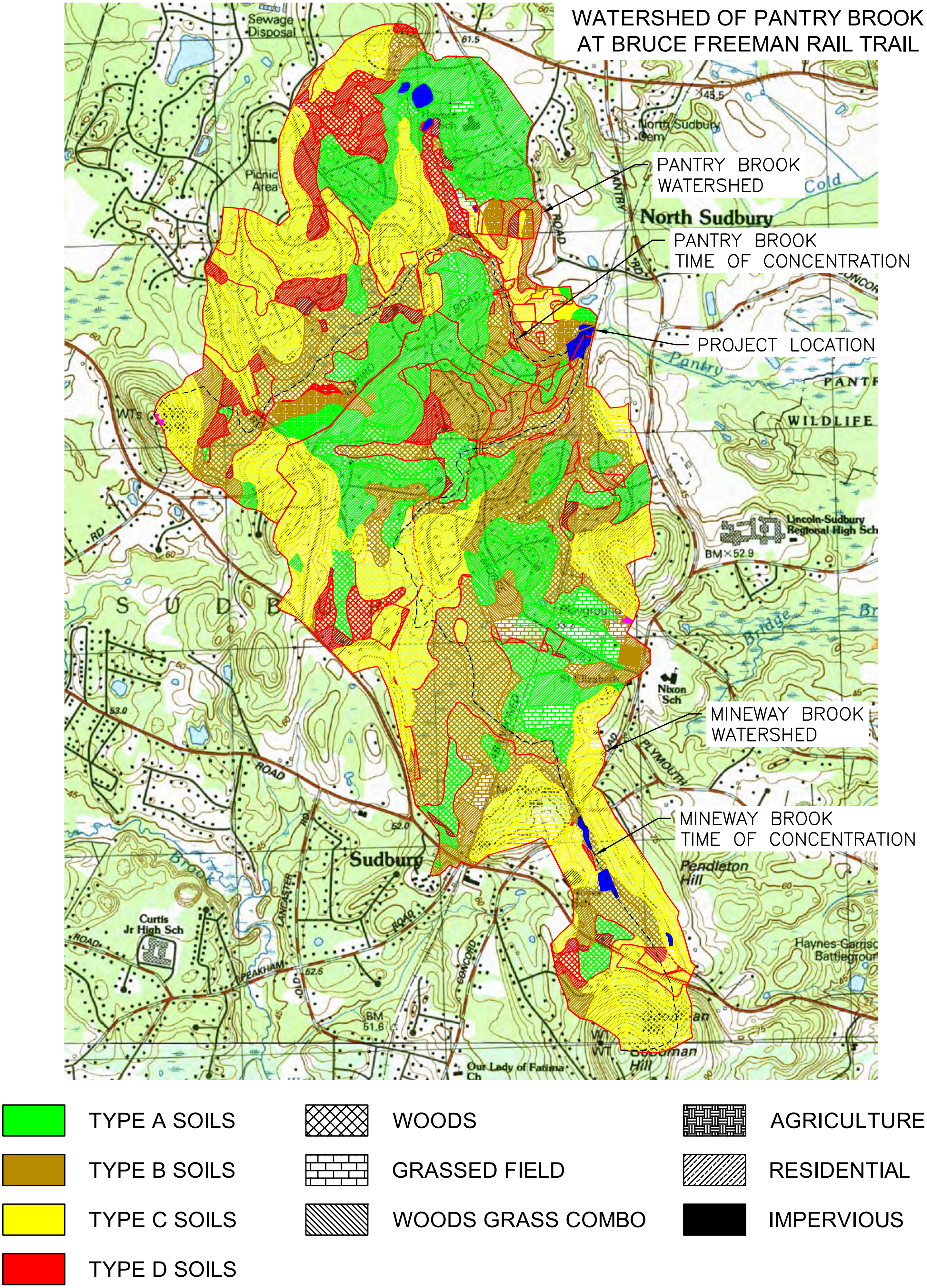
Small scale terrain

APPENDIX 6.2:

WATERSHED PLANS & USGS MAPS

Watershed Delineation Map

USGS Map – Maynard, MA


WATERSHED OF PANTRY BROOK
AT BRUCE FREEMAN RAIL TRAIL
PANTRY BROOK WATERSHED
PANTRY BROOK TIME OF CONCENTRATION
PROJECT LOCATION
MINEWAY BROOK WATERSHED
MINEWAY BROOK TIME OF CONCENTRATION
Sewage Disposal
Picnic Area
North Sudbury
Cold
Pantry
WILDLIFE
Lincoln-Sudbury Regional High Sch
BM×52.9
WTs
S U D B
Nixon Sch
Bridge
PLYMOUTH
ROAD
Sudbury
Pendleton Hill
Curtis Jr High Sch
PEAKHAM
LANCASTER
CONCORD
BM 51.6
Our Lady of Fatima Ch
TYPE A SOILS
TYPE B SOILS
TYPE C SOILS
TYPE D SOILS
WOODS
GRASSED FIELD
WOODS GRASS COMBO
AGRICULTURE
RESIDENTIAL
IMPERVIOUS

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS
WILLIAM F. CALLAHAN, COMMISSIONER

MASSACHUSETTS
(MIDDLESEX COUNTY)
MAYNARD QUADRANGLE
7½-MINUTE SERIES

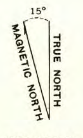
Mapped, edited, and published by the Geological Survey

Control by USGS, USC&GS, and Mass. Geodetic Survey

Culture and drainage in part compiled from aerial photographs. Surveyed 1941. Revised 1950

Polyconic projection. 1927 North American datum
10,000-foot grid based on Massachusetts (Mainland) coordinate system

1000-meter Universal Transverse Mercator grid ticks, zone 19, shown in blue



APPROXIMATE MEAN DECLINATION, 1950

SCALE 1:24000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, WASHINGTON 25, D. C.
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

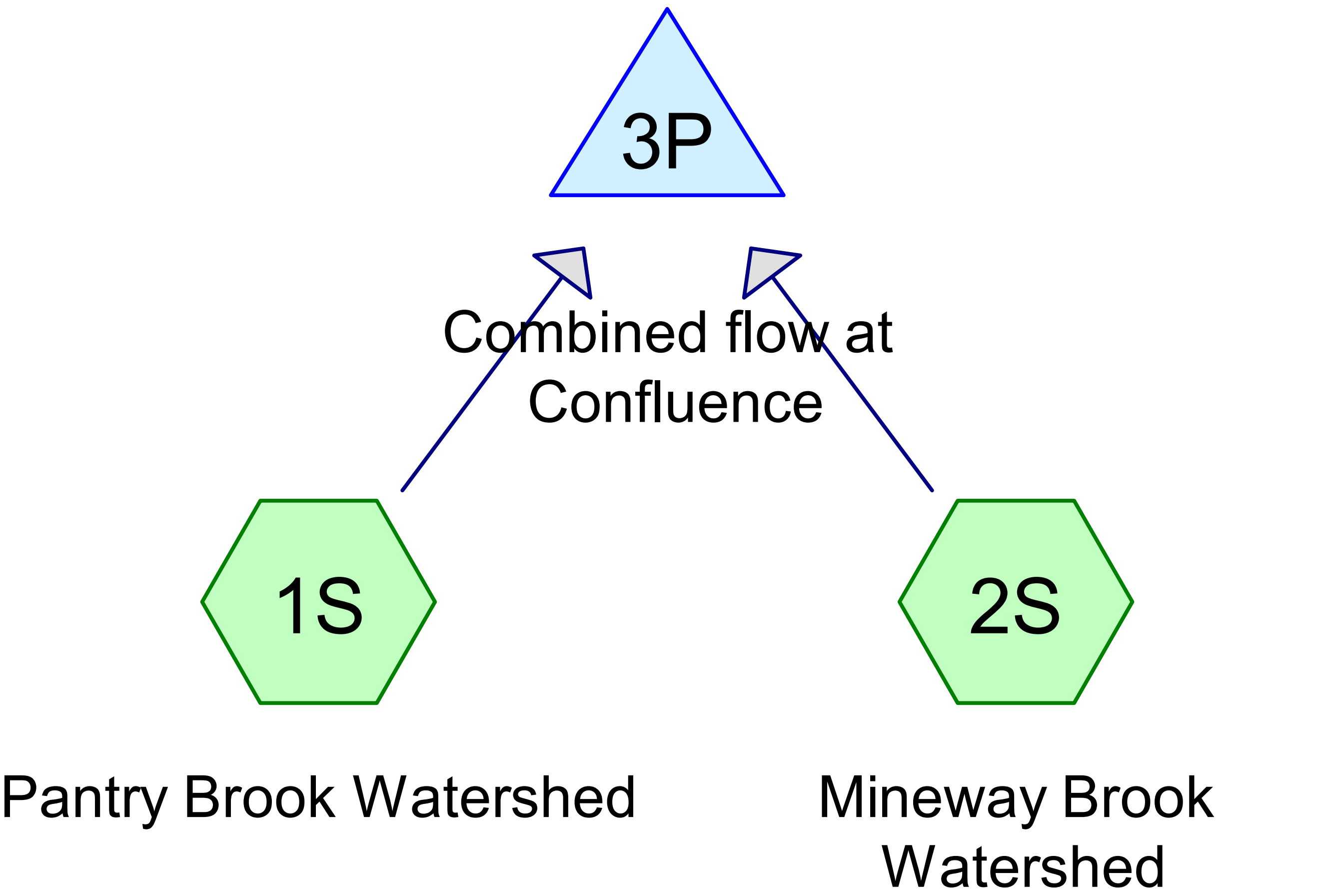
ROAD CLASSIFICATION

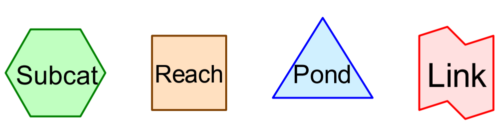
HARD-SURFACE ALL WEATHER ROADS		DRY WEATHER ROADS	
Heavy-duty	4 LANE / 6 LANE	Improved dirt	
Medium-duty	4 LANE / 6 LANE	Unimproved dirt	
U. S. Route		State Route	

MAYNARD, MASS.
N4222.5—W7122.5/7.5
1950

APPENDIX 6.3:

HYDROLOGIC MODEL AND RESULTS





Drainage Diagram for Sudbury
Prepared by Jacobs Enineering
HydroCAD® 9.00 s/n 02907 © 2009 HydroCAD Software Solutions LLC

Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
23.705	30	Meadow, non-grazed, HSG A (1S, 2S)
132.207	30	Woods, Good, HSG A (1S, 2S)
8.229	32	Woods/grass comb., Good, HSG A (1S, 2S)
52.403	46	2 acre lots, 12% imp, HSG A (1S, 2S)
228.814	51	1 acre lots, 20% imp, HSG A (1S, 2S)
265.641	55	Woods, Good, HSG B (1S, 2S)
8.481	58	Legumes, straight row, Good, HSG A (1S)
14.222	58	Meadow, non-grazed, HSG B (2S)
16.818	58	Woods/grass comb., Good, HSG B (1S, 2S)
9.265	65	2 acre lots, 12% imp, HSG B (1S, 2S)
119.698	68	1 acre lots, 20% imp, HSG B (1S, 2S)
180.987	70	Woods, Good, HSG C (1S, 2S)
21.325	71	Meadow, non-grazed, HSG C (1S, 2S)
6.142	72	1/3 acre lots, 30% imp, HSG B (2S)
16.163	72	Legumes, straight row, Good, HSG B (1S)
7.114	72	Woods/grass comb., Good, HSG C (1S, 2S)
6.230	77	1/8 acre lots, 65% imp, HSG A (1S)
22.463	77	2 acre lots, 12% imp, HSG C (1S, 2S)
38.187	77	Woods, Good, HSG D (1S, 2S)
0.962	78	Meadow, non-grazed, HSG D (1S)
310.787	79	1 acre lots, 20% imp, HSG C (1S, 2S)
1.606	79	Woods/grass comb., Good, HSG D (2S)
4.339	81	Legumes, straight row, Good, HSG C (1S)
3.996	82	2 acre lots, 12% imp, HSG D (1S, 2S)
2.834	83	1/4 acre lots, 38% imp, HSG C (2S)
52.228	84	1 acre lots, 20% imp, HSG D (1S, 2S)
0.434	85	1/8 acre lots, 65% imp, HSG B (2S)
0.349	85	Legumes, straight row, Good, HSG D (1S)
8.481	90	1/8 acre lots, 65% imp, HSG C (2S)
44.134	92	Paved roads w/open ditches, 50% imp, HSG C (1S, 2S)
3.060	98	Roofs/Pavd parking (1S, 2S)
10.894	98	Water Surface (1S, 2S)

Summary for Subcatchment 1S: Pantry Brook Watershed

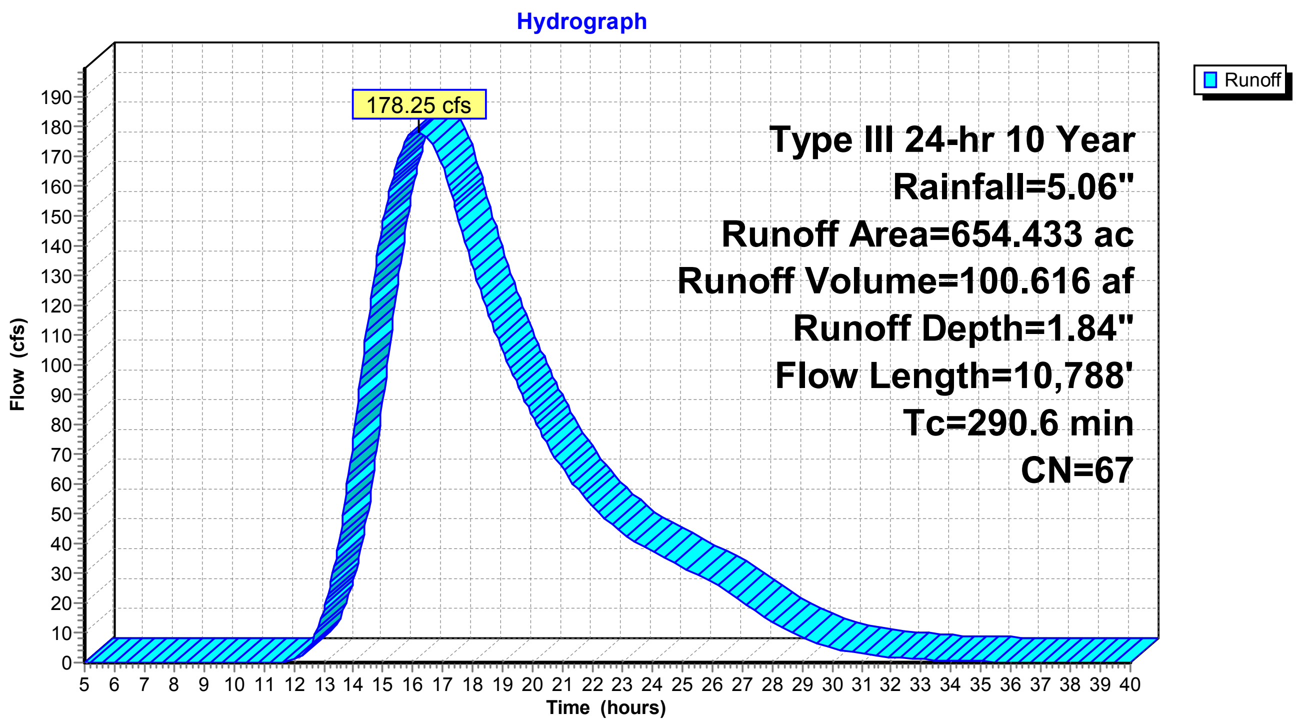
Runoff = 178.25 cfs @ 16.14 hrs, Volume= 100.616 af, Depth= 1.84"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs
Type III 24-hr 10 Year Rainfall=5.06"

	Area (ac)	CN	Description
	19.888	92	Paved roads w/open ditches, 50% imp, HSG C
*	6.415	98	Water Surface
*	0.290	98	Roofs/Pavd parking
	23.838	30	Woods, Good, HSG A
	79.987	55	Woods, Good, HSG B
	38.285	70	Woods, Good, HSG C
	27.554	77	Woods, Good, HSG D
	0.237	32	Woods/grass comb., Good, HSG A
	9.763	58	Woods/grass comb., Good, HSG B
	3.413	72	Woods/grass comb., Good, HSG C
	0.000	79	Woods/grass comb., Good, HSG D
	3.179	30	Meadow, non-grazed, HSG A
	0.000	58	Meadow, non-grazed, HSG B
	1.890	71	Meadow, non-grazed, HSG C
	0.962	78	Meadow, non-grazed, HSG D
	8.481	58	Legumes, straight row, Good, HSG A
	16.163	72	Legumes, straight row, Good, HSG B
	4.339	81	Legumes, straight row, Good, HSG C
	0.349	85	Legumes, straight row, Good, HSG D
	6.230	77	1/8 acre lots, 65% imp, HSG A
	0.000	85	1/8 acre lots, 65% imp, HSG B
	0.000	90	1/8 acre lots, 65% imp, HSG C
	0.000	92	1/8 acre lots, 65% imp, HSG D
	0.000	83	1/4 acre lots, 38% imp, HSG C
	0.000	72	1/3 acre lots, 30% imp, HSG B
	115.011	51	1 acre lots, 20% imp, HSG A
	30.310	68	1 acre lots, 20% imp, HSG B
*	172.323	79	1 acre lots, 20% imp, HSG C
	37.685	84	1 acre lots, 20% imp, HSG D
	22.991	46	2 acre lots, 12% imp, HSG A
	8.109	65	2 acre lots, 12% imp, HSG B
	12.899	77	2 acre lots, 12% imp, HSG C
	3.842	82	2 acre lots, 12% imp, HSG D
	654.433	67	Weighted Average
	556.928		85.10% Pervious Area
	97.505		14.90% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
52.4	104	0.0096	0.03		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
7.0	46	0.2857	0.11		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
3.3	258	0.2692	1.30		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
5.0	483	0.1035	1.61		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
22.1	1,200	0.0208	0.90	0.30	**Parabolic Channel, Begin Wetlands** W=2.00' D=0.25' Area=0.3 sf Perim=2.1' n= 0.070 Sluggish weedy reaches w/pools
32.8	915	0.0055	0.46	0.15	**Parabolic Channel, Wetlands** W=2.00' D=0.25' Area=0.3 sf Perim=2.1' n= 0.070 Sluggish weedy reaches w/pools
101.1	3,350	0.0030	0.55	1.10	**Parabolic Channel, Wetlands** W=6.00' D=0.50' Area=2.0 sf Perim=6.1' n= 0.070 Sluggish weedy reaches w/pools
2.8	390	0.0513	2.28	4.57	**Parabolic Channel,** W=6.00' D=0.50' Area=2.0 sf Perim=6.1' n= 0.070 Sluggish weedy reaches w/pools
64.1	4,042	0.0065	1.05	3.15	**Parabolic Channel, Wetlands** W=6.00' D=0.75' Area=3.0 sf Perim=6.2' n= 0.070 Sluggish weedy reaches w/pools
290.6	10,788	Total			

Subcatchment 1S: Pantry Brook Watershed



Summary for Subcatchment 2S: Mineway Brook Watershed

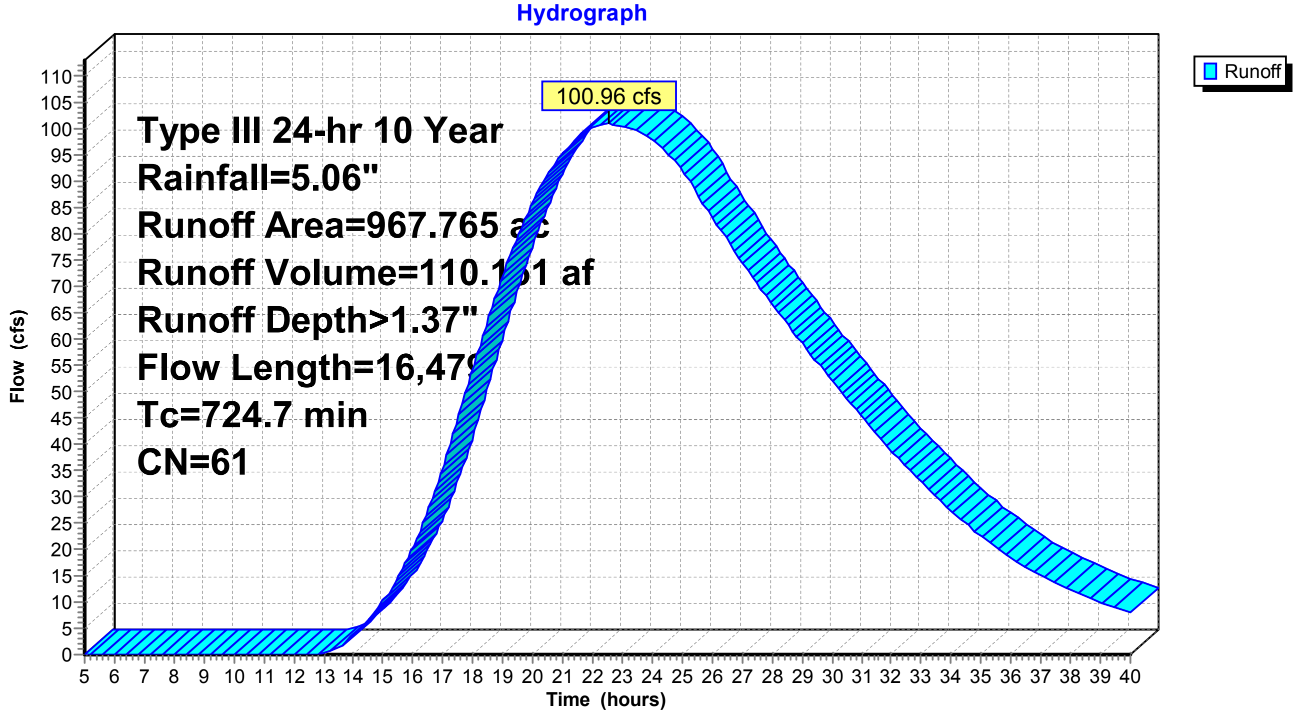
Runoff = 100.96 cfs @ 22.55 hrs, Volume= 110.151 af, Depth> 1.37"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs
Type III 24-hr 10 Year Rainfall=5.06"

	Area (ac)	CN	Description
	24.246	92	Paved roads w/open ditches, 50% imp, HSG C
*	4.479	98	Water Surface
*	2.770	98	Roofs/Pavd parking
	108.369	30	Woods, Good, HSG A
	185.654	55	Woods, Good, HSG B
	142.702	70	Woods, Good, HSG C
	10.633	77	Woods, Good, HSG D
	7.992	32	Woods/grass comb., Good, HSG A
	7.055	58	Woods/grass comb., Good, HSG B
	3.701	72	Woods/grass comb., Good, HSG C
	1.606	79	Woods/grass comb., Good, HSG D
	20.526	30	Meadow, non-grazed, HSG A
	14.222	58	Meadow, non-grazed, HSG B
	19.435	71	Meadow, non-grazed, HSG C
	0.000	78	Meadow, non-grazed, HSG D
	0.000	67	Row crops, straight row, Good, HSG A
	0.000	75	Row crops, SR + CR, Good, HSG B
	0.000	85	Row crops, SR + CR, Good, HSG D
	0.000	77	1/8 acre lots, 65% imp, HSG A
	0.434	85	1/8 acre lots, 65% imp, HSG B
	8.481	90	1/8 acre lots, 65% imp, HSG C
	0.000	92	1/8 acre lots, 65% imp, HSG D
	2.834	83	1/4 acre lots, 38% imp, HSG C
	6.142	72	1/3 acre lots, 30% imp, HSG B
	113.803	51	1 acre lots, 20% imp, HSG A
	89.388	68	1 acre lots, 20% imp, HSG B
	138.464	79	1 acre lots, 20% imp, HSG C
	14.543	84	1 acre lots, 20% imp, HSG D
	29.412	46	2 acre lots, 12% imp, HSG A
	1.156	65	2 acre lots, 12% imp, HSG B
	9.564	77	2 acre lots, 12% imp, HSG C
	0.154	82	2 acre lots, 12% imp, HSG D
	967.765	61	Weighted Average
	863.605		89.24% Pervious Area
	104.160		10.76% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
52.4	150	0.0200	0.05		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
10.2	241	0.0249	0.39		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
20.9	1,137	0.1319	0.91		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
17.8	522	0.0383	0.49		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
147.8	1,703	0.0059	0.19		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
85.0	1,342	0.0007	0.26	0.35	**Parabolic Channel, Wetlands** W=4.00' D=0.50' Area=1.3 sf Perim=4.2' n= 0.070 Sluggish weedy reaches w/pools
4.4	702	0.0570	2.65	1.33	**Parabolic Channel,** W=3.00' D=0.25' Area=0.5 sf Perim=3.1' n= 0.040 Winding stream, pools & shoals
30.0	1,145	0.0087	0.64	0.64	**Parabolic Channel, Wetlands** W=3.00' D=0.50' Area=1.0 sf Perim=3.2' n= 0.100 Very weedy reaches w/pools
284.5	5,177	0.0019	0.30	0.40	**Parabolic Channel, Wetlands** W=4.00' D=0.50' Area=1.3 sf Perim=4.2' n= 0.100 Very weedy reaches w/pools
3.1	483	0.0414	2.57	5.15	**Parabolic Channel,** W=4.00' D=0.75' Area=2.0 sf Perim=4.3' n= 0.070 Sluggish weedy reaches w/pools
46.8	2,372	0.0042	0.84	2.53	**Parabolic Channel, Wetlands & Morse Rd area** W=6.00' D=0.75' Area=3.0 sf Perim=6.2' n= 0.070 Sluggish weedy reaches w/pools
21.8	1,505	0.0053	1.15	6.13	**Parabolic Channel, Wetlands** W=8.00' D=1.00' Area=5.3 sf Perim=8.3' n= 0.070 Sluggish weedy reaches w/pools
724.7	16,479	Total			

Subcatchment 2S: Mineway Brook Watershed

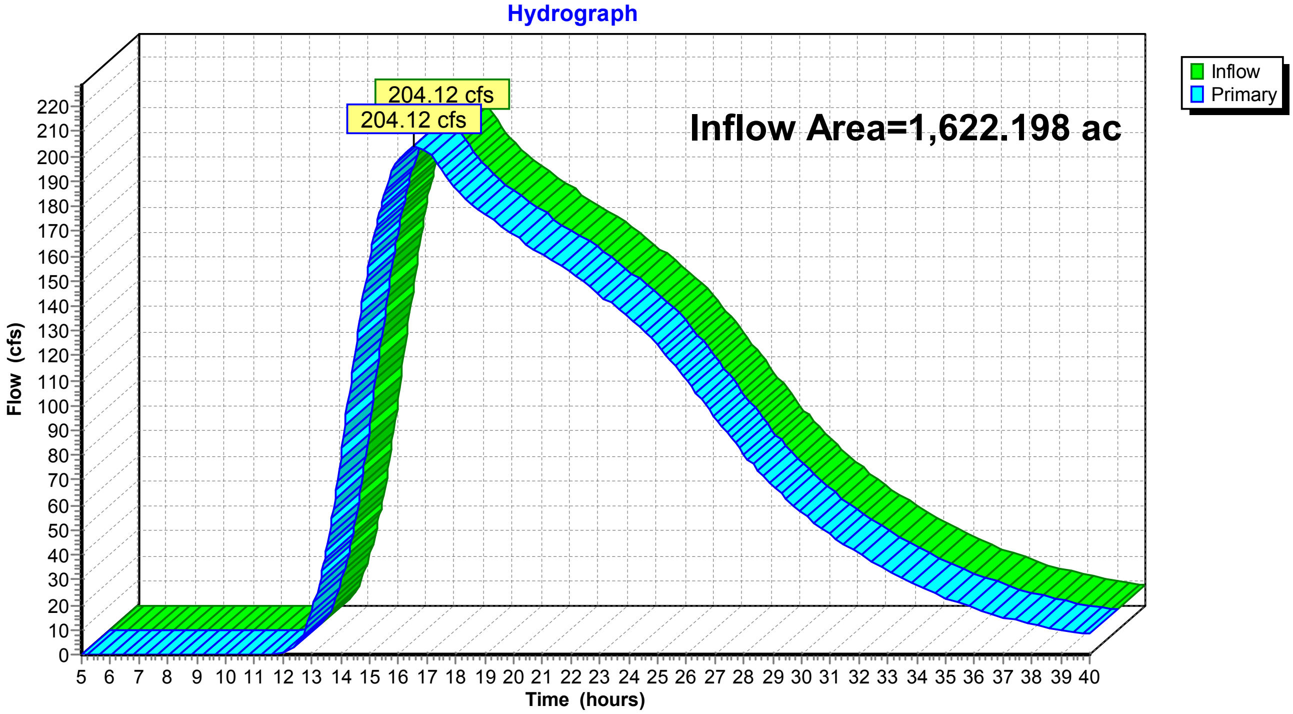


Summary for Pond 3P: Combined flow at Confluence

Inflow Area = 1,622.198 ac, 12.43% Impervious, Inflow Depth > 1.56" for 10 Year event
Inflow = 204.12 cfs @ 16.52 hrs, Volume= 210.767 af
Primary = 204.12 cfs @ 16.52 hrs, Volume= 210.767 af, Atten= 0%, Lag= 0.0 min

Routing by Dyn-Stor-Ind method, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs

Pond 3P: Combined flow at Confluence



Summary for Subcatchment 1S: Pantry Brook Watershed

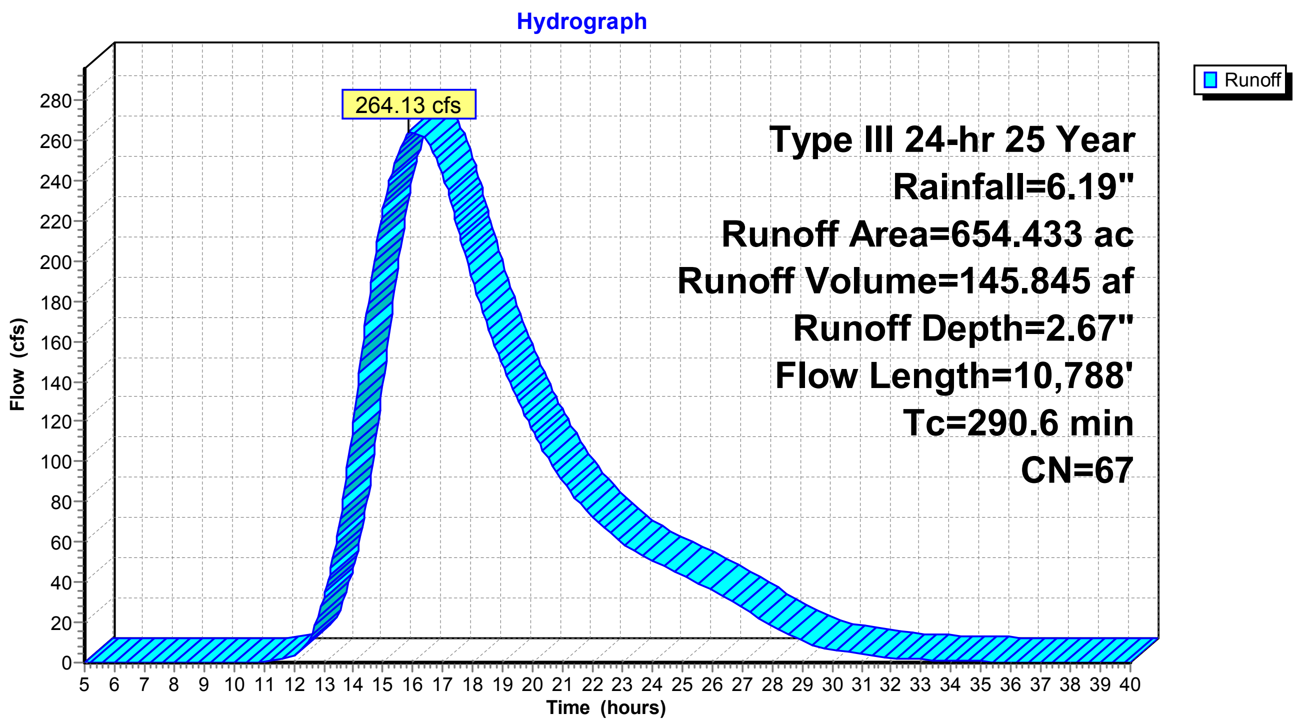
Runoff = 264.13 cfs @ 15.85 hrs, Volume= 145.845 af, Depth= 2.67"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs
Type III 24-hr 25 Year Rainfall=6.19"

	Area (ac)	CN	Description
	19.888	92	Paved roads w/open ditches, 50% imp, HSG C
*	6.415	98	Water Surface
*	0.290	98	Roofs/Pavd parking
	23.838	30	Woods, Good, HSG A
	79.987	55	Woods, Good, HSG B
	38.285	70	Woods, Good, HSG C
	27.554	77	Woods, Good, HSG D
	0.237	32	Woods/grass comb., Good, HSG A
	9.763	58	Woods/grass comb., Good, HSG B
	3.413	72	Woods/grass comb., Good, HSG C
	0.000	79	Woods/grass comb., Good, HSG D
	3.179	30	Meadow, non-grazed, HSG A
	0.000	58	Meadow, non-grazed, HSG B
	1.890	71	Meadow, non-grazed, HSG C
	0.962	78	Meadow, non-grazed, HSG D
	8.481	58	Legumes, straight row, Good, HSG A
	16.163	72	Legumes, straight row, Good, HSG B
	4.339	81	Legumes, straight row, Good, HSG C
	0.349	85	Legumes, straight row, Good, HSG D
	6.230	77	1/8 acre lots, 65% imp, HSG A
	0.000	85	1/8 acre lots, 65% imp, HSG B
	0.000	90	1/8 acre lots, 65% imp, HSG C
	0.000	92	1/8 acre lots, 65% imp, HSG D
	0.000	83	1/4 acre lots, 38% imp, HSG C
	0.000	72	1/3 acre lots, 30% imp, HSG B
	115.011	51	1 acre lots, 20% imp, HSG A
	30.310	68	1 acre lots, 20% imp, HSG B
*	172.323	79	1 acre lots, 20% imp, HSG C
	37.685	84	1 acre lots, 20% imp, HSG D
	22.991	46	2 acre lots, 12% imp, HSG A
	8.109	65	2 acre lots, 12% imp, HSG B
	12.899	77	2 acre lots, 12% imp, HSG C
	3.842	82	2 acre lots, 12% imp, HSG D
	654.433	67	Weighted Average
	556.928		85.10% Pervious Area
	97.505		14.90% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
52.4	104	0.0096	0.03		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
7.0	46	0.2857	0.11		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
3.3	258	0.2692	1.30		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
5.0	483	0.1035	1.61		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
22.1	1,200	0.0208	0.90	0.30	**Parabolic Channel, Begin Wetlands** W=2.00' D=0.25' Area=0.3 sf Perim=2.1' n= 0.070 Sluggish weedy reaches w/pools
32.8	915	0.0055	0.46	0.15	**Parabolic Channel, Wetlands** W=2.00' D=0.25' Area=0.3 sf Perim=2.1' n= 0.070 Sluggish weedy reaches w/pools
101.1	3,350	0.0030	0.55	1.10	**Parabolic Channel, Wetlands** W=6.00' D=0.50' Area=2.0 sf Perim=6.1' n= 0.070 Sluggish weedy reaches w/pools
2.8	390	0.0513	2.28	4.57	**Parabolic Channel,** W=6.00' D=0.50' Area=2.0 sf Perim=6.1' n= 0.070 Sluggish weedy reaches w/pools
64.1	4,042	0.0065	1.05	3.15	**Parabolic Channel, Wetlands** W=6.00' D=0.75' Area=3.0 sf Perim=6.2' n= 0.070 Sluggish weedy reaches w/pools
290.6	10,788	Total			

Subcatchment 1S: Pantry Brook Watershed



Summary for Subcatchment 2S: Mineway Brook Watershed

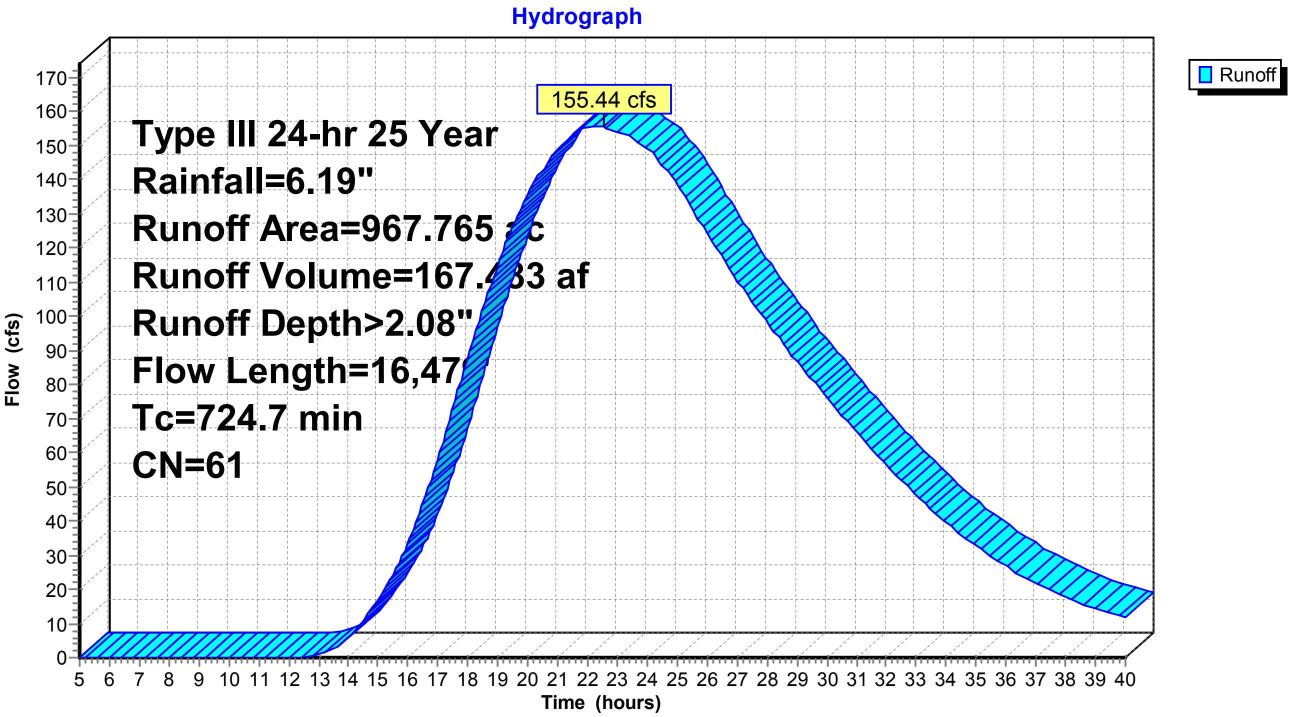
Runoff = 155.44 cfs @ 22.51 hrs, Volume= 167.483 af, Depth> 2.08"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs
Type III 24-hr 25 Year Rainfall=6.19"

	Area (ac)	CN	Description
	24.246	92	Paved roads w/open ditches, 50% imp, HSG C
*	4.479	98	Water Surface
*	2.770	98	Roofs/Pavd parking
	108.369	30	Woods, Good, HSG A
	185.654	55	Woods, Good, HSG B
	142.702	70	Woods, Good, HSG C
	10.633	77	Woods, Good, HSG D
	7.992	32	Woods/grass comb., Good, HSG A
	7.055	58	Woods/grass comb., Good, HSG B
	3.701	72	Woods/grass comb., Good, HSG C
	1.606	79	Woods/grass comb., Good, HSG D
	20.526	30	Meadow, non-grazed, HSG A
	14.222	58	Meadow, non-grazed, HSG B
	19.435	71	Meadow, non-grazed, HSG C
	0.000	78	Meadow, non-grazed, HSG D
	0.000	67	Row crops, straight row, Good, HSG A
	0.000	75	Row crops, SR + CR, Good, HSG B
	0.000	85	Row crops, SR + CR, Good, HSG D
	0.000	77	1/8 acre lots, 65% imp, HSG A
	0.434	85	1/8 acre lots, 65% imp, HSG B
	8.481	90	1/8 acre lots, 65% imp, HSG C
	0.000	92	1/8 acre lots, 65% imp, HSG D
	2.834	83	1/4 acre lots, 38% imp, HSG C
	6.142	72	1/3 acre lots, 30% imp, HSG B
	113.803	51	1 acre lots, 20% imp, HSG A
	89.388	68	1 acre lots, 20% imp, HSG B
	138.464	79	1 acre lots, 20% imp, HSG C
	14.543	84	1 acre lots, 20% imp, HSG D
	29.412	46	2 acre lots, 12% imp, HSG A
	1.156	65	2 acre lots, 12% imp, HSG B
	9.564	77	2 acre lots, 12% imp, HSG C
	0.154	82	2 acre lots, 12% imp, HSG D
	967.765	61	Weighted Average
	863.605		89.24% Pervious Area
	104.160		10.76% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
52.4	150	0.0200	0.05		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
10.2	241	0.0249	0.39		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
20.9	1,137	0.1319	0.91		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
17.8	522	0.0383	0.49		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
147.8	1,703	0.0059	0.19		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
85.0	1,342	0.0007	0.26	0.35	**Parabolic Channel, Wetlands** W=4.00' D=0.50' Area=1.3 sf Perim=4.2' n= 0.070 Sluggish weedy reaches w/pools
4.4	702	0.0570	2.65	1.33	**Parabolic Channel,** W=3.00' D=0.25' Area=0.5 sf Perim=3.1' n= 0.040 Winding stream, pools & shoals
30.0	1,145	0.0087	0.64	0.64	**Parabolic Channel, Wetlands** W=3.00' D=0.50' Area=1.0 sf Perim=3.2' n= 0.100 Very weedy reaches w/pools
284.5	5,177	0.0019	0.30	0.40	**Parabolic Channel, Wetlands** W=4.00' D=0.50' Area=1.3 sf Perim=4.2' n= 0.100 Very weedy reaches w/pools
3.1	483	0.0414	2.57	5.15	**Parabolic Channel,** W=4.00' D=0.75' Area=2.0 sf Perim=4.3' n= 0.070 Sluggish weedy reaches w/pools
46.8	2,372	0.0042	0.84	2.53	**Parabolic Channel, Wetlands & Morse Rd area** W=6.00' D=0.75' Area=3.0 sf Perim=6.2' n= 0.070 Sluggish weedy reaches w/pools
21.8	1,505	0.0053	1.15	6.13	**Parabolic Channel, Wetlands** W=8.00' D=1.00' Area=5.3 sf Perim=8.3' n= 0.070 Sluggish weedy reaches w/pools
724.7	16,479	Total			

Subcatchment 2S: Mineway Brook Watershed

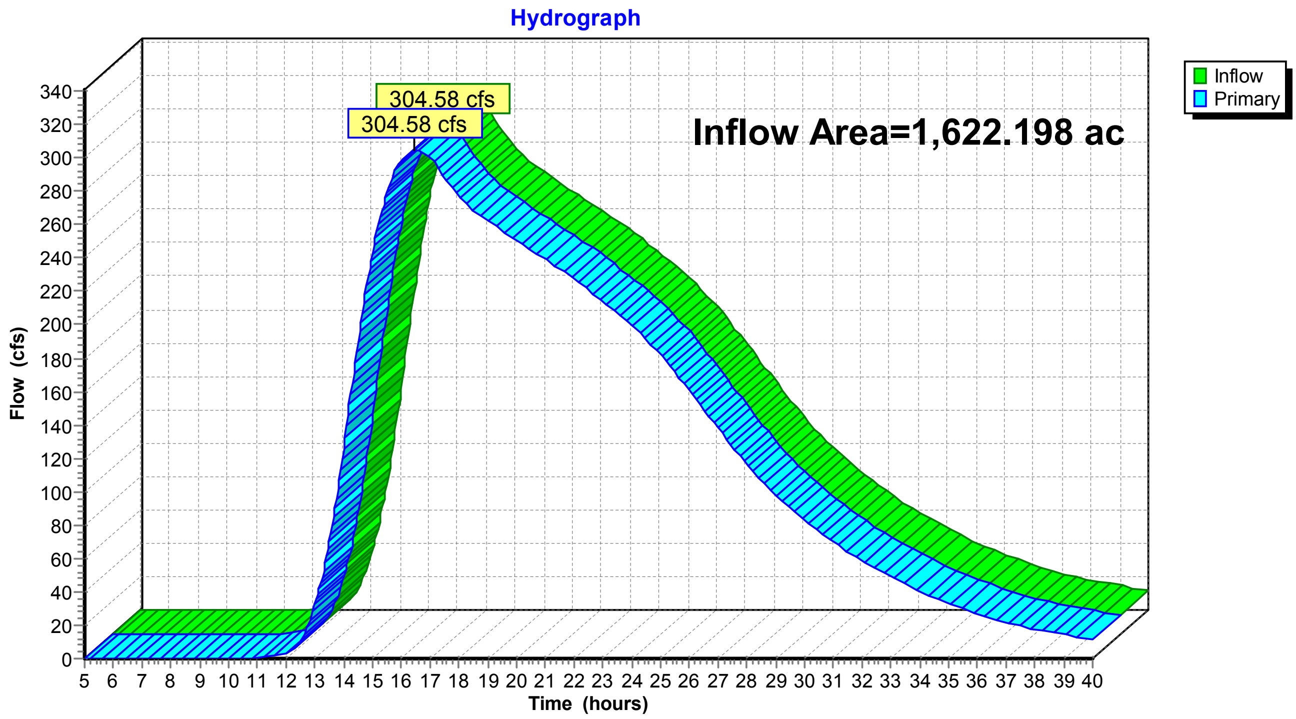


Summary for Pond 3P: Combined flow at Confluence

Inflow Area = 1,622.198 ac, 12.43% Impervious, Inflow Depth > 2.32" for 25 Year event
Inflow = 304.58 cfs @ 16.49 hrs, Volume= 313.327 af
Primary = 304.58 cfs @ 16.49 hrs, Volume= 313.327 af, Atten= 0%, Lag= 0.0 min

Routing by Dyn-Stor-Ind method, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs

Pond 3P: Combined flow at Confluence



Summary for Subcatchment 1S: Pantry Brook Watershed

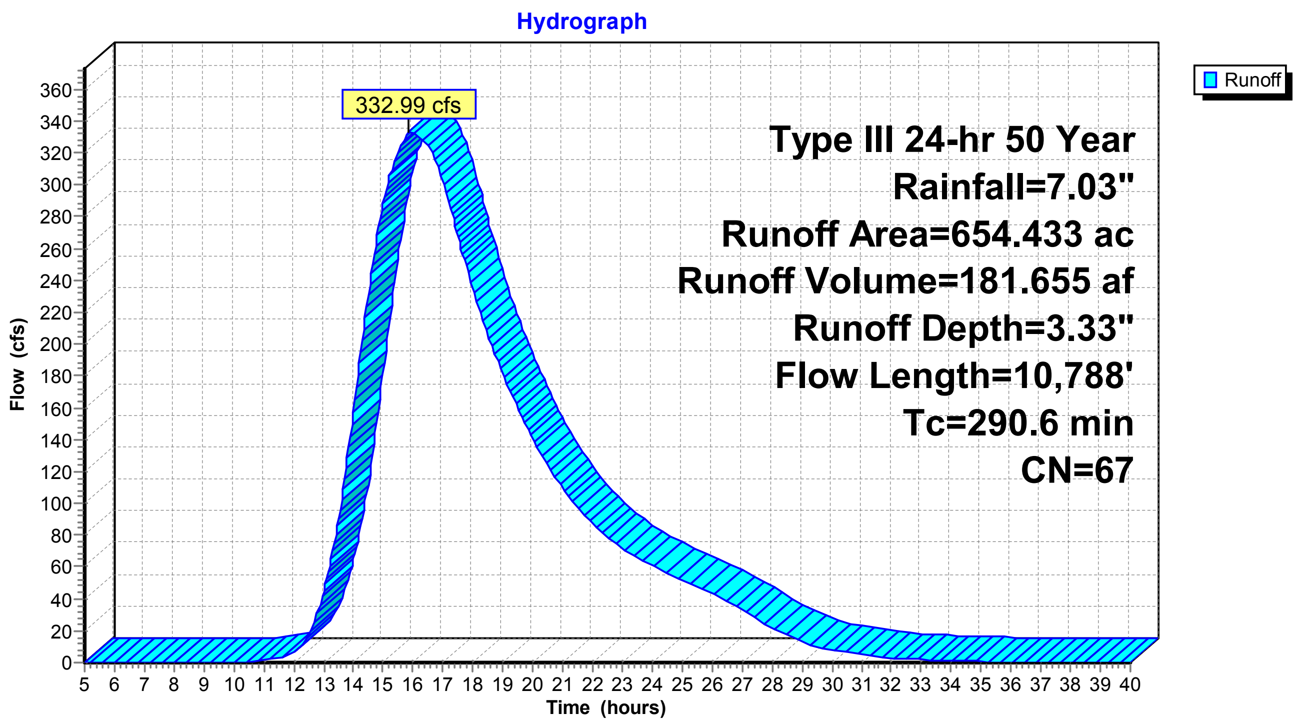
Runoff = 332.99 cfs @ 15.86 hrs, Volume= 181.655 af, Depth= 3.33"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs
Type III 24-hr 50 Year Rainfall=7.03"

	Area (ac)	CN	Description
	19.888	92	Paved roads w/open ditches, 50% imp, HSG C
*	6.415	98	Water Surface
*	0.290	98	Roofs/Pavd parking
	23.838	30	Woods, Good, HSG A
	79.987	55	Woods, Good, HSG B
	38.285	70	Woods, Good, HSG C
	27.554	77	Woods, Good, HSG D
	0.237	32	Woods/grass comb., Good, HSG A
	9.763	58	Woods/grass comb., Good, HSG B
	3.413	72	Woods/grass comb., Good, HSG C
	0.000	79	Woods/grass comb., Good, HSG D
	3.179	30	Meadow, non-grazed, HSG A
	0.000	58	Meadow, non-grazed, HSG B
	1.890	71	Meadow, non-grazed, HSG C
	0.962	78	Meadow, non-grazed, HSG D
	8.481	58	Legumes, straight row, Good, HSG A
	16.163	72	Legumes, straight row, Good, HSG B
	4.339	81	Legumes, straight row, Good, HSG C
	0.349	85	Legumes, straight row, Good, HSG D
	6.230	77	1/8 acre lots, 65% imp, HSG A
	0.000	85	1/8 acre lots, 65% imp, HSG B
	0.000	90	1/8 acre lots, 65% imp, HSG C
	0.000	92	1/8 acre lots, 65% imp, HSG D
	0.000	83	1/4 acre lots, 38% imp, HSG C
	0.000	72	1/3 acre lots, 30% imp, HSG B
	115.011	51	1 acre lots, 20% imp, HSG A
	30.310	68	1 acre lots, 20% imp, HSG B
*	172.323	79	1 acre lots, 20% imp, HSG C
	37.685	84	1 acre lots, 20% imp, HSG D
	22.991	46	2 acre lots, 12% imp, HSG A
	8.109	65	2 acre lots, 12% imp, HSG B
	12.899	77	2 acre lots, 12% imp, HSG C
	3.842	82	2 acre lots, 12% imp, HSG D
	654.433	67	Weighted Average
	556.928		85.10% Pervious Area
	97.505		14.90% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
52.4	104	0.0096	0.03		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
7.0	46	0.2857	0.11		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
3.3	258	0.2692	1.30		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
5.0	483	0.1035	1.61		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
22.1	1,200	0.0208	0.90	0.30	**Parabolic Channel, Begin Wetlands** W=2.00' D=0.25' Area=0.3 sf Perim=2.1' n= 0.070 Sluggish weedy reaches w/pools
32.8	915	0.0055	0.46	0.15	**Parabolic Channel, Wetlands** W=2.00' D=0.25' Area=0.3 sf Perim=2.1' n= 0.070 Sluggish weedy reaches w/pools
101.1	3,350	0.0030	0.55	1.10	**Parabolic Channel, Wetlands** W=6.00' D=0.50' Area=2.0 sf Perim=6.1' n= 0.070 Sluggish weedy reaches w/pools
2.8	390	0.0513	2.28	4.57	**Parabolic Channel,** W=6.00' D=0.50' Area=2.0 sf Perim=6.1' n= 0.070 Sluggish weedy reaches w/pools
64.1	4,042	0.0065	1.05	3.15	**Parabolic Channel, Wetlands** W=6.00' D=0.75' Area=3.0 sf Perim=6.2' n= 0.070 Sluggish weedy reaches w/pools
290.6	10,788	Total			

Subcatchment 1S: Pantry Brook Watershed



Summary for Subcatchment 2S: Mineway Brook Watershed

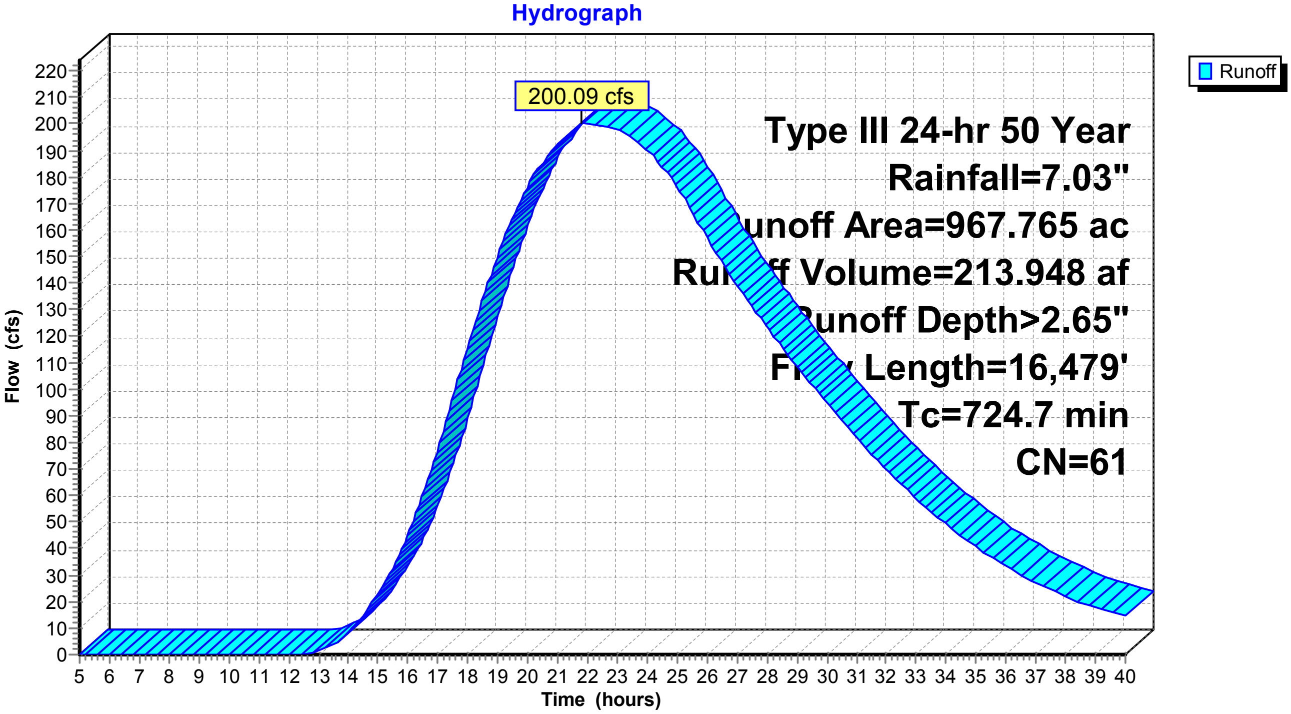
Runoff = 200.09 cfs @ 21.78 hrs, Volume= 213.948 af, Depth> 2.65"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs
Type III 24-hr 50 Year Rainfall=7.03"

	Area (ac)	CN	Description
	24.246	92	Paved roads w/open ditches, 50% imp, HSG C
*	4.479	98	Water Surface
*	2.770	98	Roofs/Pavd parking
	108.369	30	Woods, Good, HSG A
	185.654	55	Woods, Good, HSG B
	142.702	70	Woods, Good, HSG C
	10.633	77	Woods, Good, HSG D
	7.992	32	Woods/grass comb., Good, HSG A
	7.055	58	Woods/grass comb., Good, HSG B
	3.701	72	Woods/grass comb., Good, HSG C
	1.606	79	Woods/grass comb., Good, HSG D
	20.526	30	Meadow, non-grazed, HSG A
	14.222	58	Meadow, non-grazed, HSG B
	19.435	71	Meadow, non-grazed, HSG C
	0.000	78	Meadow, non-grazed, HSG D
	0.000	67	Row crops, straight row, Good, HSG A
	0.000	75	Row crops, SR + CR, Good, HSG B
	0.000	85	Row crops, SR + CR, Good, HSG D
	0.000	77	1/8 acre lots, 65% imp, HSG A
	0.434	85	1/8 acre lots, 65% imp, HSG B
	8.481	90	1/8 acre lots, 65% imp, HSG C
	0.000	92	1/8 acre lots, 65% imp, HSG D
	2.834	83	1/4 acre lots, 38% imp, HSG C
	6.142	72	1/3 acre lots, 30% imp, HSG B
	113.803	51	1 acre lots, 20% imp, HSG A
	89.388	68	1 acre lots, 20% imp, HSG B
	138.464	79	1 acre lots, 20% imp, HSG C
	14.543	84	1 acre lots, 20% imp, HSG D
	29.412	46	2 acre lots, 12% imp, HSG A
	1.156	65	2 acre lots, 12% imp, HSG B
	9.564	77	2 acre lots, 12% imp, HSG C
	0.154	82	2 acre lots, 12% imp, HSG D
	967.765	61	Weighted Average
	863.605		89.24% Pervious Area
	104.160		10.76% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
52.4	150	0.0200	0.05		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
10.2	241	0.0249	0.39		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
20.9	1,137	0.1319	0.91		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
17.8	522	0.0383	0.49		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
147.8	1,703	0.0059	0.19		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
85.0	1,342	0.0007	0.26	0.35	**Parabolic Channel, Wetlands** W=4.00' D=0.50' Area=1.3 sf Perim=4.2' n= 0.070 Sluggish weedy reaches w/pools
4.4	702	0.0570	2.65	1.33	**Parabolic Channel,** W=3.00' D=0.25' Area=0.5 sf Perim=3.1' n= 0.040 Winding stream, pools & shoals
30.0	1,145	0.0087	0.64	0.64	**Parabolic Channel, Wetlands** W=3.00' D=0.50' Area=1.0 sf Perim=3.2' n= 0.100 Very weedy reaches w/pools
284.5	5,177	0.0019	0.30	0.40	**Parabolic Channel, Wetlands** W=4.00' D=0.50' Area=1.3 sf Perim=4.2' n= 0.100 Very weedy reaches w/pools
3.1	483	0.0414	2.57	5.15	**Parabolic Channel,** W=4.00' D=0.75' Area=2.0 sf Perim=4.3' n= 0.070 Sluggish weedy reaches w/pools
46.8	2,372	0.0042	0.84	2.53	**Parabolic Channel, Wetlands & Morse Rd area** W=6.00' D=0.75' Area=3.0 sf Perim=6.2' n= 0.070 Sluggish weedy reaches w/pools
21.8	1,505	0.0053	1.15	6.13	**Parabolic Channel, Wetlands** W=8.00' D=1.00' Area=5.3 sf Perim=8.3' n= 0.070 Sluggish weedy reaches w/pools
724.7	16,479	Total			

Subcatchment 2S: Mineway Brook Watershed

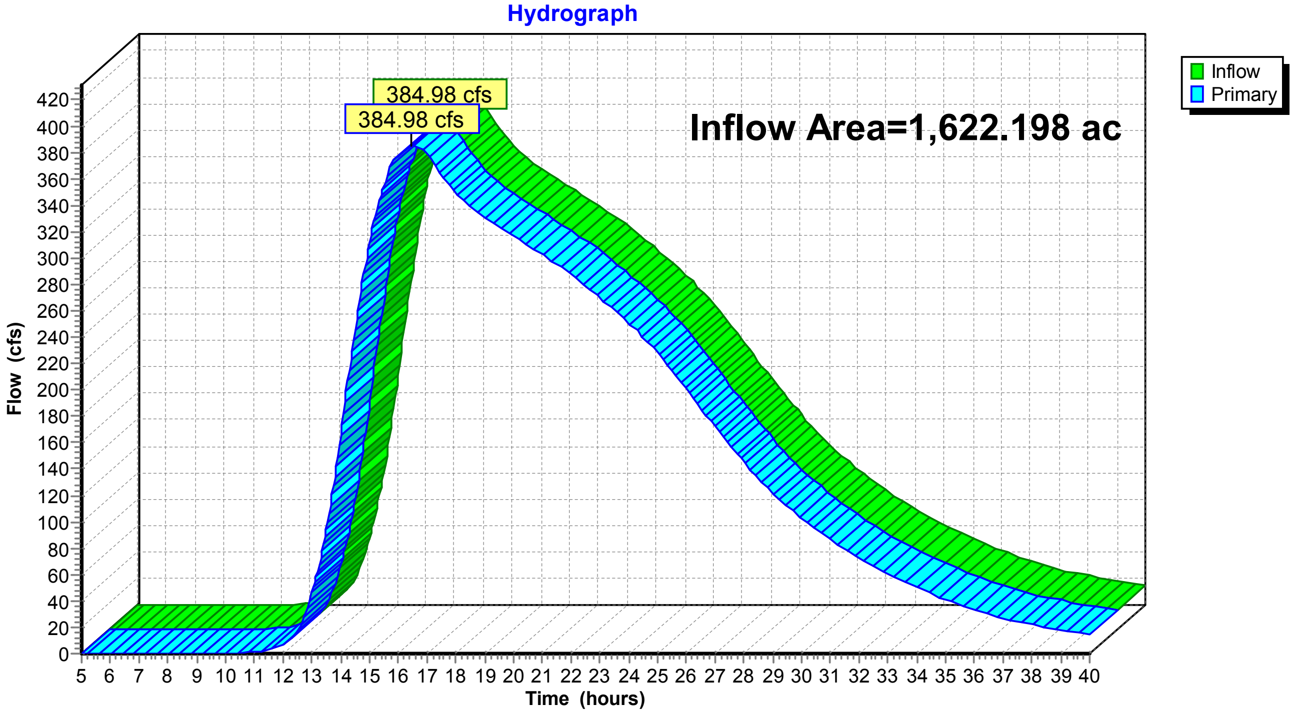


Summary for Pond 3P: Combined flow at Confluence

Inflow Area = 1,622.198 ac, 12.43% Impervious, Inflow Depth > 2.93" for 50 Year event
Inflow = 384.98 cfs @ 16.48 hrs, Volume= 395.603 af
Primary = 384.98 cfs @ 16.48 hrs, Volume= 395.603 af, Atten= 0%, Lag= 0.0 min

Routing by Dyn-Stor-Ind method, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs

Pond 3P: Combined flow at Confluence



Summary for Subcatchment 1S: Pantry Brook Watershed

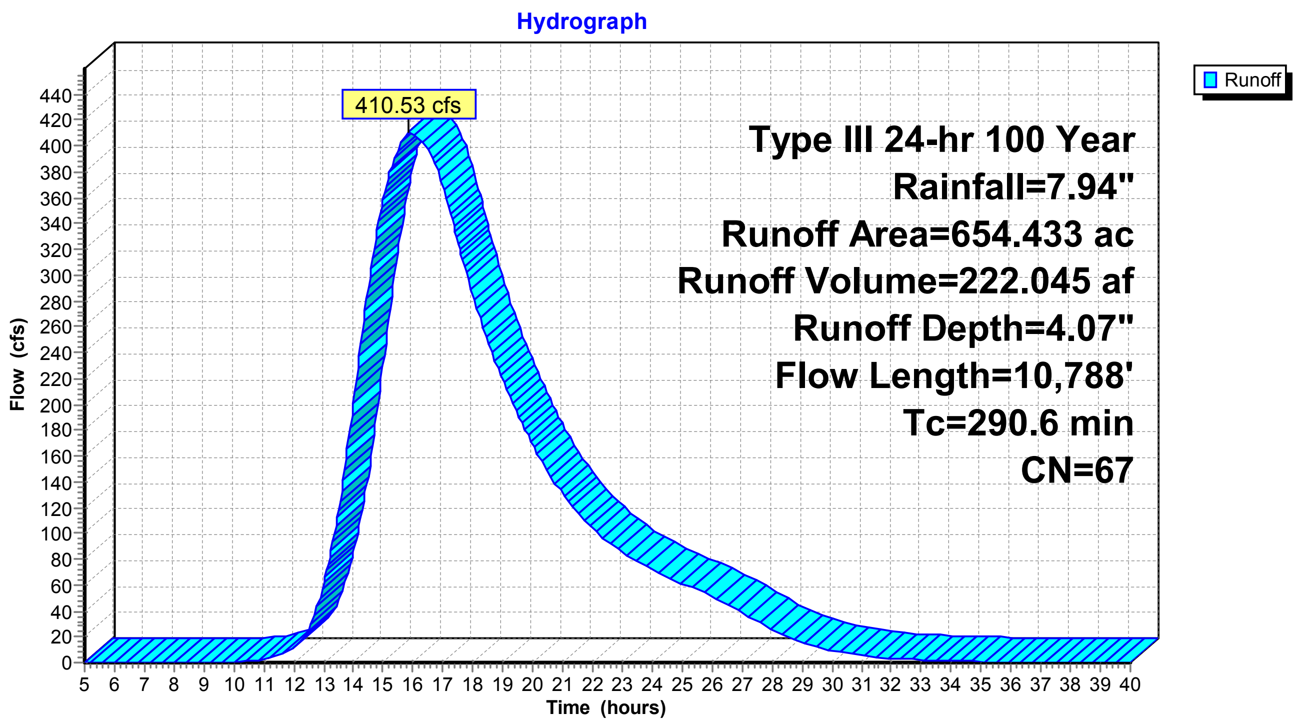
Runoff = 410.53 cfs @ 15.85 hrs, Volume= 222.045 af, Depth= 4.07"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs
Type III 24-hr 100 Year Rainfall=7.94"

	Area (ac)	CN	Description
	19.888	92	Paved roads w/open ditches, 50% imp, HSG C
*	6.415	98	Water Surface
*	0.290	98	Roofs/Pavd parking
	23.838	30	Woods, Good, HSG A
	79.987	55	Woods, Good, HSG B
	38.285	70	Woods, Good, HSG C
	27.554	77	Woods, Good, HSG D
	0.237	32	Woods/grass comb., Good, HSG A
	9.763	58	Woods/grass comb., Good, HSG B
	3.413	72	Woods/grass comb., Good, HSG C
	0.000	79	Woods/grass comb., Good, HSG D
	3.179	30	Meadow, non-grazed, HSG A
	0.000	58	Meadow, non-grazed, HSG B
	1.890	71	Meadow, non-grazed, HSG C
	0.962	78	Meadow, non-grazed, HSG D
	8.481	58	Legumes, straight row, Good, HSG A
	16.163	72	Legumes, straight row, Good, HSG B
	4.339	81	Legumes, straight row, Good, HSG C
	0.349	85	Legumes, straight row, Good, HSG D
	6.230	77	1/8 acre lots, 65% imp, HSG A
	0.000	85	1/8 acre lots, 65% imp, HSG B
	0.000	90	1/8 acre lots, 65% imp, HSG C
	0.000	92	1/8 acre lots, 65% imp, HSG D
	0.000	83	1/4 acre lots, 38% imp, HSG C
	0.000	72	1/3 acre lots, 30% imp, HSG B
	115.011	51	1 acre lots, 20% imp, HSG A
	30.310	68	1 acre lots, 20% imp, HSG B
*	172.323	79	1 acre lots, 20% imp, HSG C
	37.685	84	1 acre lots, 20% imp, HSG D
	22.991	46	2 acre lots, 12% imp, HSG A
	8.109	65	2 acre lots, 12% imp, HSG B
	12.899	77	2 acre lots, 12% imp, HSG C
	3.842	82	2 acre lots, 12% imp, HSG D
	654.433	67	Weighted Average
	556.928		85.10% Pervious Area
	97.505		14.90% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
52.4	104	0.0096	0.03		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
7.0	46	0.2857	0.11		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
3.3	258	0.2692	1.30		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
5.0	483	0.1035	1.61		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
22.1	1,200	0.0208	0.90	0.30	**Parabolic Channel, Begin Wetlands** W=2.00' D=0.25' Area=0.3 sf Perim=2.1' n= 0.070 Sluggish weedy reaches w/pools
32.8	915	0.0055	0.46	0.15	**Parabolic Channel, Wetlands** W=2.00' D=0.25' Area=0.3 sf Perim=2.1' n= 0.070 Sluggish weedy reaches w/pools
101.1	3,350	0.0030	0.55	1.10	**Parabolic Channel, Wetlands** W=6.00' D=0.50' Area=2.0 sf Perim=6.1' n= 0.070 Sluggish weedy reaches w/pools
2.8	390	0.0513	2.28	4.57	**Parabolic Channel,** W=6.00' D=0.50' Area=2.0 sf Perim=6.1' n= 0.070 Sluggish weedy reaches w/pools
64.1	4,042	0.0065	1.05	3.15	**Parabolic Channel, Wetlands** W=6.00' D=0.75' Area=3.0 sf Perim=6.2' n= 0.070 Sluggish weedy reaches w/pools
290.6	10,788	Total			

Subcatchment 1S: Pantry Brook Watershed



Summary for Subcatchment 2S: Mineway Brook Watershed

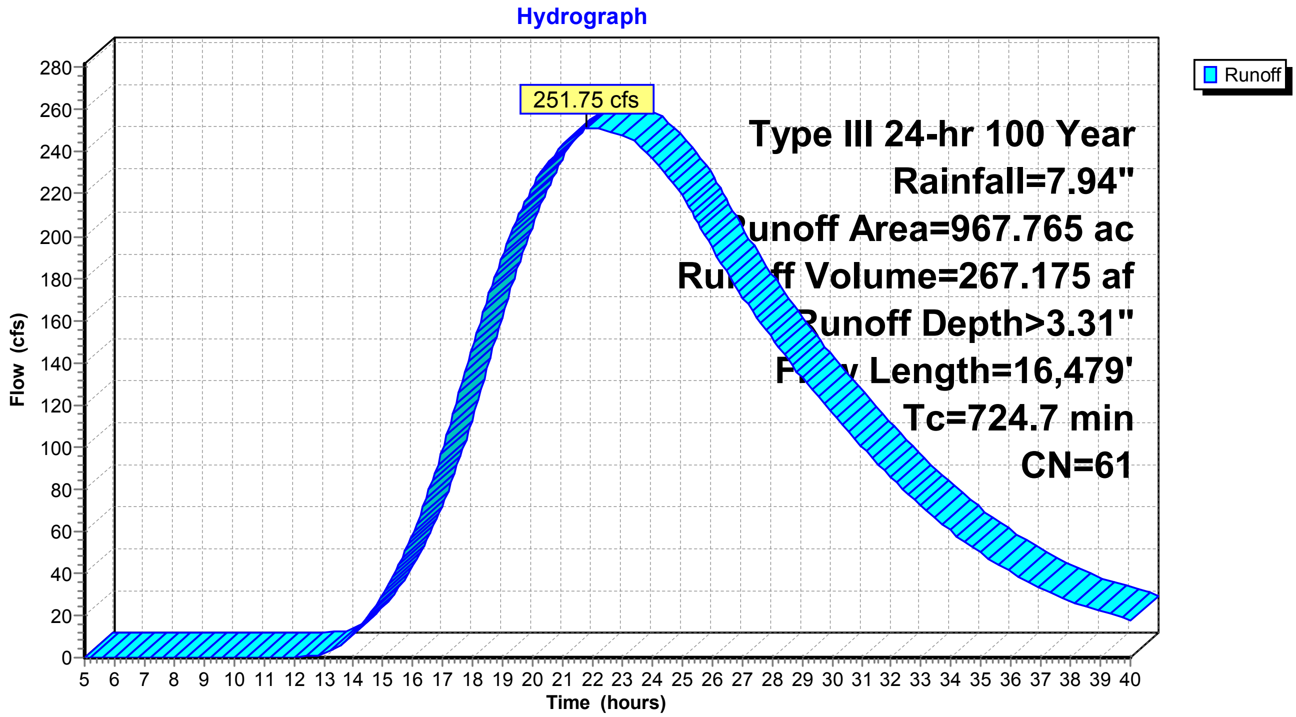
Runoff = 251.75 cfs @ 21.77 hrs, Volume= 267.175 af, Depth> 3.31"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs
Type III 24-hr 100 Year Rainfall=7.94"

	Area (ac)	CN	Description
	24.246	92	Paved roads w/open ditches, 50% imp, HSG C
*	4.479	98	Water Surface
*	2.770	98	Roofs/Pavd parking
	108.369	30	Woods, Good, HSG A
	185.654	55	Woods, Good, HSG B
	142.702	70	Woods, Good, HSG C
	10.633	77	Woods, Good, HSG D
	7.992	32	Woods/grass comb., Good, HSG A
	7.055	58	Woods/grass comb., Good, HSG B
	3.701	72	Woods/grass comb., Good, HSG C
	1.606	79	Woods/grass comb., Good, HSG D
	20.526	30	Meadow, non-grazed, HSG A
	14.222	58	Meadow, non-grazed, HSG B
	19.435	71	Meadow, non-grazed, HSG C
	0.000	78	Meadow, non-grazed, HSG D
	0.000	67	Row crops, straight row, Good, HSG A
	0.000	75	Row crops, SR + CR, Good, HSG B
	0.000	85	Row crops, SR + CR, Good, HSG D
	0.000	77	1/8 acre lots, 65% imp, HSG A
	0.434	85	1/8 acre lots, 65% imp, HSG B
	8.481	90	1/8 acre lots, 65% imp, HSG C
	0.000	92	1/8 acre lots, 65% imp, HSG D
	2.834	83	1/4 acre lots, 38% imp, HSG C
	6.142	72	1/3 acre lots, 30% imp, HSG B
	113.803	51	1 acre lots, 20% imp, HSG A
	89.388	68	1 acre lots, 20% imp, HSG B
	138.464	79	1 acre lots, 20% imp, HSG C
	14.543	84	1 acre lots, 20% imp, HSG D
	29.412	46	2 acre lots, 12% imp, HSG A
	1.156	65	2 acre lots, 12% imp, HSG B
	9.564	77	2 acre lots, 12% imp, HSG C
	0.154	82	2 acre lots, 12% imp, HSG D
	967.765	61	Weighted Average
	863.605		89.24% Pervious Area
	104.160		10.76% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
52.4	150	0.0200	0.05		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
10.2	241	0.0249	0.39		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
20.9	1,137	0.1319	0.91		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
17.8	522	0.0383	0.49		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
147.8	1,703	0.0059	0.19		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
85.0	1,342	0.0007	0.26	0.35	**Parabolic Channel, Wetlands** W=4.00' D=0.50' Area=1.3 sf Perim=4.2' n= 0.070 Sluggish weedy reaches w/pools
4.4	702	0.0570	2.65	1.33	**Parabolic Channel,** W=3.00' D=0.25' Area=0.5 sf Perim=3.1' n= 0.040 Winding stream, pools & shoals
30.0	1,145	0.0087	0.64	0.64	**Parabolic Channel, Wetlands** W=3.00' D=0.50' Area=1.0 sf Perim=3.2' n= 0.100 Very weedy reaches w/pools
284.5	5,177	0.0019	0.30	0.40	**Parabolic Channel, Wetlands** W=4.00' D=0.50' Area=1.3 sf Perim=4.2' n= 0.100 Very weedy reaches w/pools
3.1	483	0.0414	2.57	5.15	**Parabolic Channel,** W=4.00' D=0.75' Area=2.0 sf Perim=4.3' n= 0.070 Sluggish weedy reaches w/pools
46.8	2,372	0.0042	0.84	2.53	**Parabolic Channel, Wetlands & Morse Rd area** W=6.00' D=0.75' Area=3.0 sf Perim=6.2' n= 0.070 Sluggish weedy reaches w/pools
21.8	1,505	0.0053	1.15	6.13	**Parabolic Channel, Wetlands** W=8.00' D=1.00' Area=5.3 sf Perim=8.3' n= 0.070 Sluggish weedy reaches w/pools
724.7	16,479	Total			

Subcatchment 2S: Mineway Brook Watershed

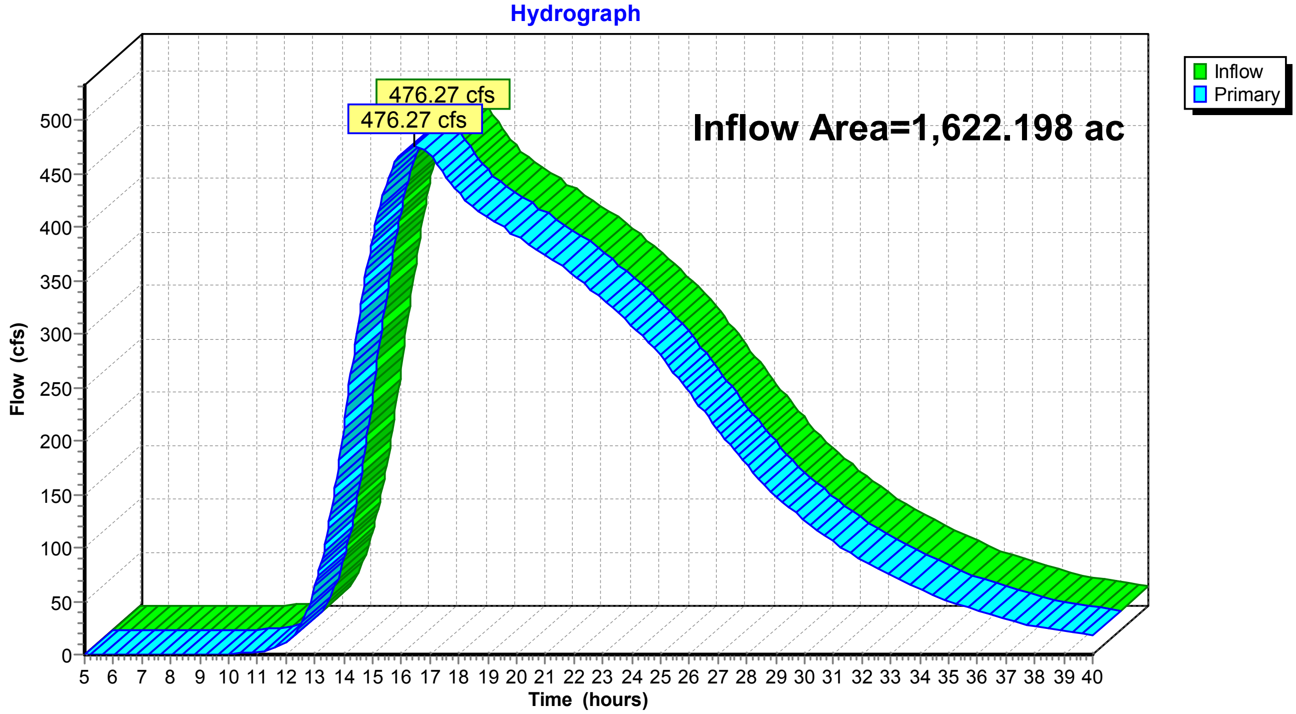


Summary for Pond 3P: Combined flow at Confluence

Inflow Area = 1,622.198 ac, 12.43% Impervious, Inflow Depth > 3.62" for 100 Year event
Inflow = 476.27 cfs @ 16.47 hrs, Volume= 489.220 af
Primary = 476.27 cfs @ 16.47 hrs, Volume= 489.220 af, Atten= 0%, Lag= 0.0 min

Routing by Dyn-Stor-Ind method, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs

Pond 3P: Combined flow at Confluence



Summary for Subcatchment 1S: Pantry Brook Watershed

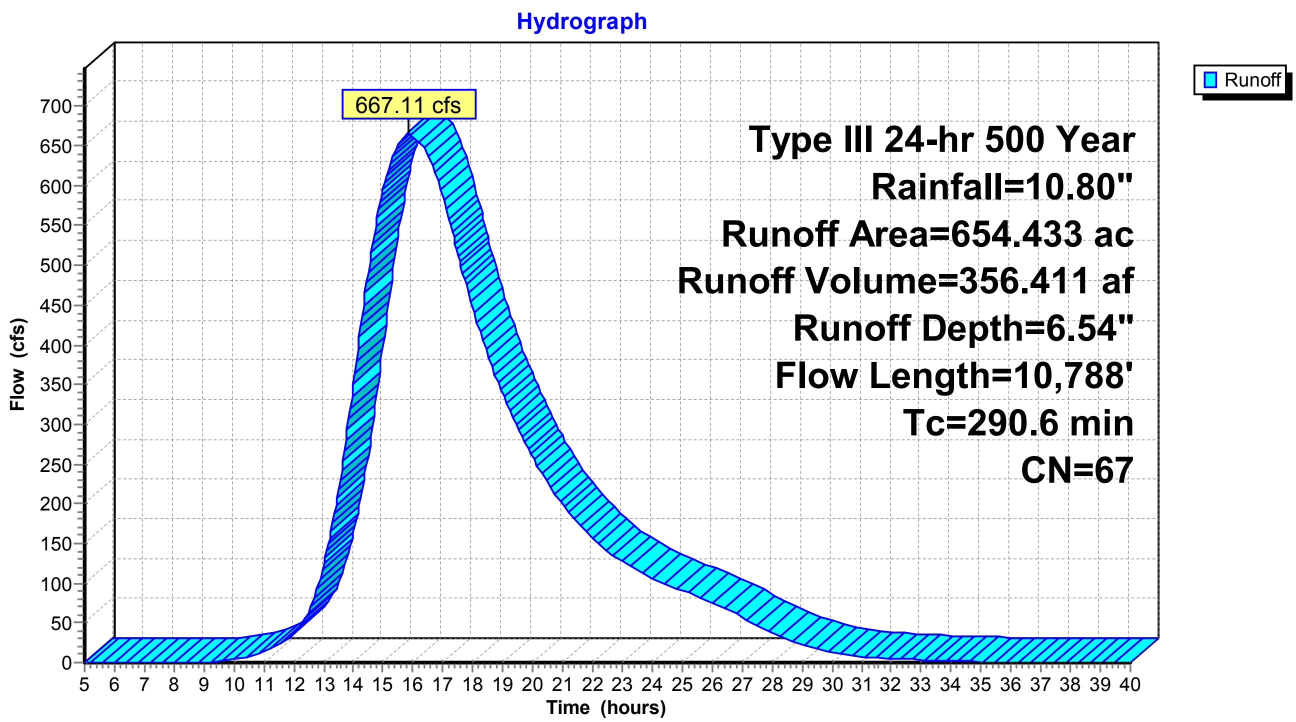
Runoff = 667.11 cfs @ 15.83 hrs, Volume= 356.411 af, Depth= 6.54"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs
Type III 24-hr 500 Year Rainfall=10.80"

	Area (ac)	CN	Description
	19.888	92	Paved roads w/open ditches, 50% imp, HSG C
*	6.415	98	Water Surface
*	0.290	98	Roofs/Pavd parking
	23.838	30	Woods, Good, HSG A
	79.987	55	Woods, Good, HSG B
	38.285	70	Woods, Good, HSG C
	27.554	77	Woods, Good, HSG D
	0.237	32	Woods/grass comb., Good, HSG A
	9.763	58	Woods/grass comb., Good, HSG B
	3.413	72	Woods/grass comb., Good, HSG C
	0.000	79	Woods/grass comb., Good, HSG D
	3.179	30	Meadow, non-grazed, HSG A
	0.000	58	Meadow, non-grazed, HSG B
	1.890	71	Meadow, non-grazed, HSG C
	0.962	78	Meadow, non-grazed, HSG D
	8.481	58	Legumes, straight row, Good, HSG A
	16.163	72	Legumes, straight row, Good, HSG B
	4.339	81	Legumes, straight row, Good, HSG C
	0.349	85	Legumes, straight row, Good, HSG D
	6.230	77	1/8 acre lots, 65% imp, HSG A
	0.000	85	1/8 acre lots, 65% imp, HSG B
	0.000	90	1/8 acre lots, 65% imp, HSG C
	0.000	92	1/8 acre lots, 65% imp, HSG D
	0.000	83	1/4 acre lots, 38% imp, HSG C
	0.000	72	1/3 acre lots, 30% imp, HSG B
	115.011	51	1 acre lots, 20% imp, HSG A
	30.310	68	1 acre lots, 20% imp, HSG B
*	172.323	79	1 acre lots, 20% imp, HSG C
	37.685	84	1 acre lots, 20% imp, HSG D
	22.991	46	2 acre lots, 12% imp, HSG A
	8.109	65	2 acre lots, 12% imp, HSG B
	12.899	77	2 acre lots, 12% imp, HSG C
	3.842	82	2 acre lots, 12% imp, HSG D
	654.433	67	Weighted Average
	556.928		85.10% Pervious Area
	97.505		14.90% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
52.4	104	0.0096	0.03		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
7.0	46	0.2857	0.11		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
3.3	258	0.2692	1.30		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
5.0	483	0.1035	1.61		**Shallow Concentrated Flow,** Woodland Kv= 5.0 fps
22.1	1,200	0.0208	0.90	0.30	**Parabolic Channel, Begin Wetlands** W=2.00' D=0.25' Area=0.3 sf Perim=2.1' n= 0.070 Sluggish weedy reaches w/pools
32.8	915	0.0055	0.46	0.15	**Parabolic Channel, Wetlands** W=2.00' D=0.25' Area=0.3 sf Perim=2.1' n= 0.070 Sluggish weedy reaches w/pools
101.1	3,350	0.0030	0.55	1.10	**Parabolic Channel, Wetlands** W=6.00' D=0.50' Area=2.0 sf Perim=6.1' n= 0.070 Sluggish weedy reaches w/pools
2.8	390	0.0513	2.28	4.57	**Parabolic Channel,** W=6.00' D=0.50' Area=2.0 sf Perim=6.1' n= 0.070 Sluggish weedy reaches w/pools
64.1	4,042	0.0065	1.05	3.15	**Parabolic Channel, Wetlands** W=6.00' D=0.75' Area=3.0 sf Perim=6.2' n= 0.070 Sluggish weedy reaches w/pools
290.6	10,788	Total			

Subcatchment 1S: Pantry Brook Watershed



Summary for Subcatchment 2S: Mineway Brook Watershed

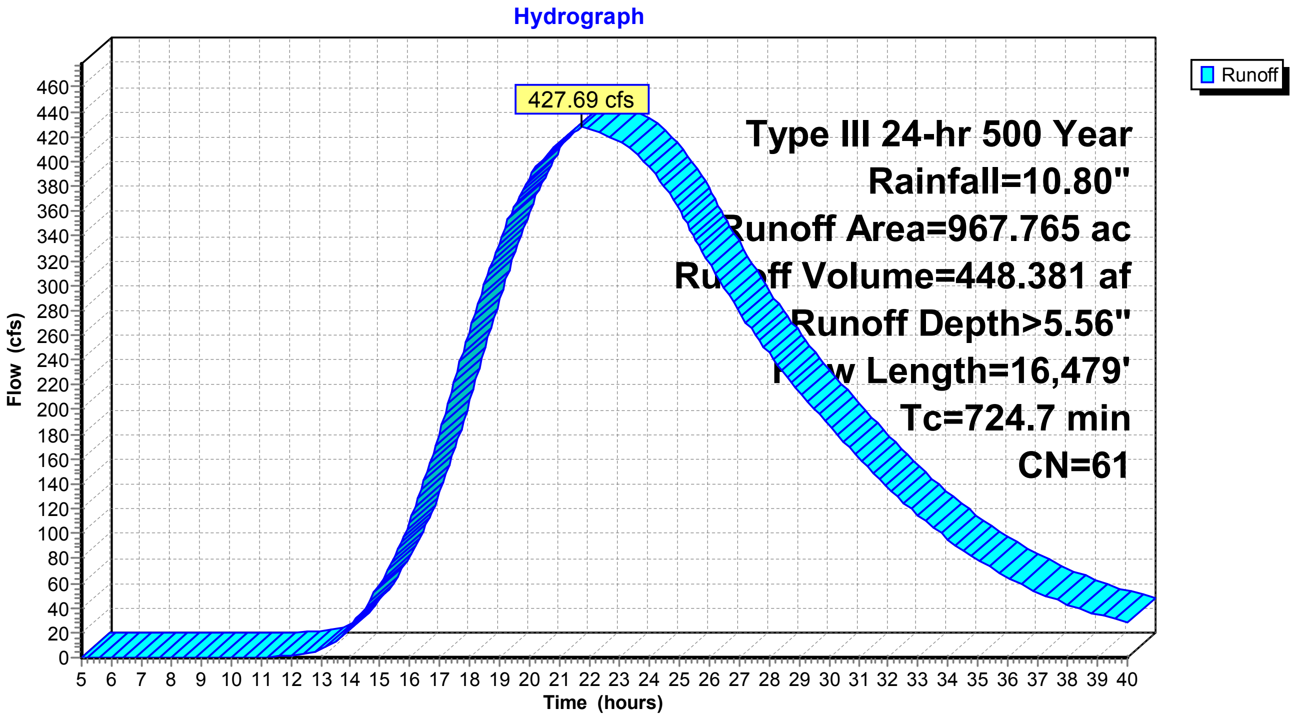
Runoff = 427.69 cfs @ 21.76 hrs, Volume= 448.381 af, Depth> 5.56"

Runoff by SCS TR-20 method, UH=SCS, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs
Type III 24-hr 500 Year Rainfall=10.80"

	Area (ac)	CN	Description
	24.246	92	Paved roads w/open ditches, 50% imp, HSG C
*	4.479	98	Water Surface
*	2.770	98	Roofs/Pavd parking
	108.369	30	Woods, Good, HSG A
	185.654	55	Woods, Good, HSG B
	142.702	70	Woods, Good, HSG C
	10.633	77	Woods, Good, HSG D
	7.992	32	Woods/grass comb., Good, HSG A
	7.055	58	Woods/grass comb., Good, HSG B
	3.701	72	Woods/grass comb., Good, HSG C
	1.606	79	Woods/grass comb., Good, HSG D
	20.526	30	Meadow, non-grazed, HSG A
	14.222	58	Meadow, non-grazed, HSG B
	19.435	71	Meadow, non-grazed, HSG C
	0.000	78	Meadow, non-grazed, HSG D
	0.000	67	Row crops, straight row, Good, HSG A
	0.000	75	Row crops, SR + CR, Good, HSG B
	0.000	85	Row crops, SR + CR, Good, HSG D
	0.000	77	1/8 acre lots, 65% imp, HSG A
	0.434	85	1/8 acre lots, 65% imp, HSG B
	8.481	90	1/8 acre lots, 65% imp, HSG C
	0.000	92	1/8 acre lots, 65% imp, HSG D
	2.834	83	1/4 acre lots, 38% imp, HSG C
	6.142	72	1/3 acre lots, 30% imp, HSG B
	113.803	51	1 acre lots, 20% imp, HSG A
	89.388	68	1 acre lots, 20% imp, HSG B
	138.464	79	1 acre lots, 20% imp, HSG C
	14.543	84	1 acre lots, 20% imp, HSG D
	29.412	46	2 acre lots, 12% imp, HSG A
	1.156	65	2 acre lots, 12% imp, HSG B
	9.564	77	2 acre lots, 12% imp, HSG C
	0.154	82	2 acre lots, 12% imp, HSG D
	967.765	61	Weighted Average
	863.605		89.24% Pervious Area
	104.160		10.76% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
52.4	150	0.0200	0.05		**Sheet Flow,** Woods: Dense underbrush n= 0.800 P2= 3.12"
10.2	241	0.0249	0.39		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
20.9	1,137	0.1319	0.91		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
17.8	522	0.0383	0.49		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
147.8	1,703	0.0059	0.19		**Shallow Concentrated Flow,** Forest w/Heavy Litter Kv= 2.5 fps
85.0	1,342	0.0007	0.26	0.35	**Parabolic Channel, Wetlands** W=4.00' D=0.50' Area=1.3 sf Perim=4.2' n= 0.070 Sluggish weedy reaches w/pools
4.4	702	0.0570	2.65	1.33	**Parabolic Channel,** W=3.00' D=0.25' Area=0.5 sf Perim=3.1' n= 0.040 Winding stream, pools & shoals
30.0	1,145	0.0087	0.64	0.64	**Parabolic Channel, Wetlands** W=3.00' D=0.50' Area=1.0 sf Perim=3.2' n= 0.100 Very weedy reaches w/pools
284.5	5,177	0.0019	0.30	0.40	**Parabolic Channel, Wetlands** W=4.00' D=0.50' Area=1.3 sf Perim=4.2' n= 0.100 Very weedy reaches w/pools
3.1	483	0.0414	2.57	5.15	**Parabolic Channel,** W=4.00' D=0.75' Area=2.0 sf Perim=4.3' n= 0.070 Sluggish weedy reaches w/pools
46.8	2,372	0.0042	0.84	2.53	**Parabolic Channel, Wetlands & Morse Rd area** W=6.00' D=0.75' Area=3.0 sf Perim=6.2' n= 0.070 Sluggish weedy reaches w/pools
21.8	1,505	0.0053	1.15	6.13	**Parabolic Channel, Wetlands** W=8.00' D=1.00' Area=5.3 sf Perim=8.3' n= 0.070 Sluggish weedy reaches w/pools
724.7	16,479	Total			

Subcatchment 2S: Mineway Brook Watershed

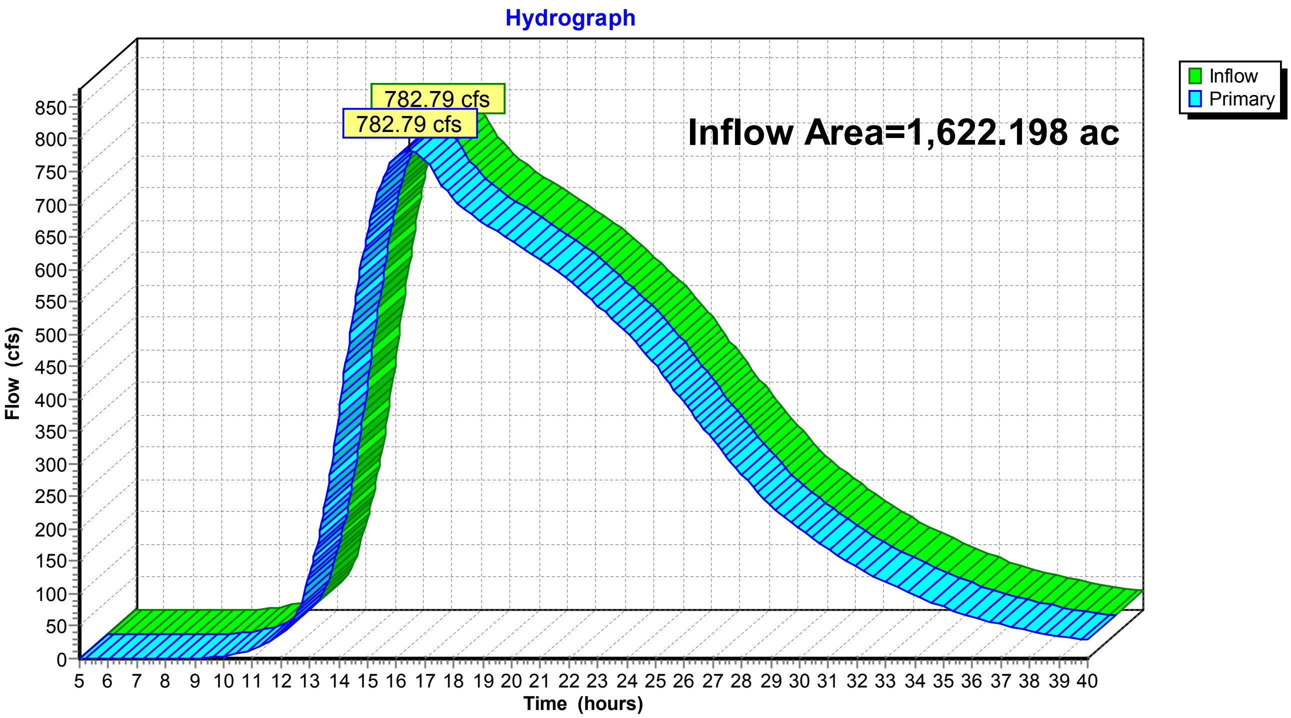


Summary for Pond 3P: Combined flow at Confluence

Inflow Area = 1,622.198 ac, 12.43% Impervious, Inflow Depth > 5.95" for 500 Year event
Inflow = 782.79 cfs @ 16.46 hrs, Volume= 804.792 af
Primary = 782.79 cfs @ 16.46 hrs, Volume= 804.792 af, Atten= 0%, Lag= 0.0 min

Routing by Dyn-Stor-Ind method, Time Span= 5.00-40.00 hrs, dt= 0.05 hrs

Pond 3P: Combined flow at Confluence



APPENDIX 6.4:

FLOOD INSURANCE RATE MAPS

FLOOD INSURANCE STUDY FLOODWAY DATA

FLOOD INSURANCE STUDY FLOOD PROFILE

$^{46}99^{000m}$N

$^{46}98^{000m}$N

42° 24' 22"

JOINS PANEL 0368

$^{3}01^{000m}$E

PROFILE BASELINE

Mineway Brook

BRIDGE

71° 24' 22"

MAP SCALE 1" = 500'

250 0 500 1000 FEET

METERS

NATIONAL FLOOD INSURANCE PROGRAM

NFIP

PANEL 0366F

FIRM

FLOOD INSURANCE RATE MAP

MIDDLESEX COUNTY, MASSACHUSETTS
(ALL JURISDICTIONS)

PANEL 366 OF 656

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

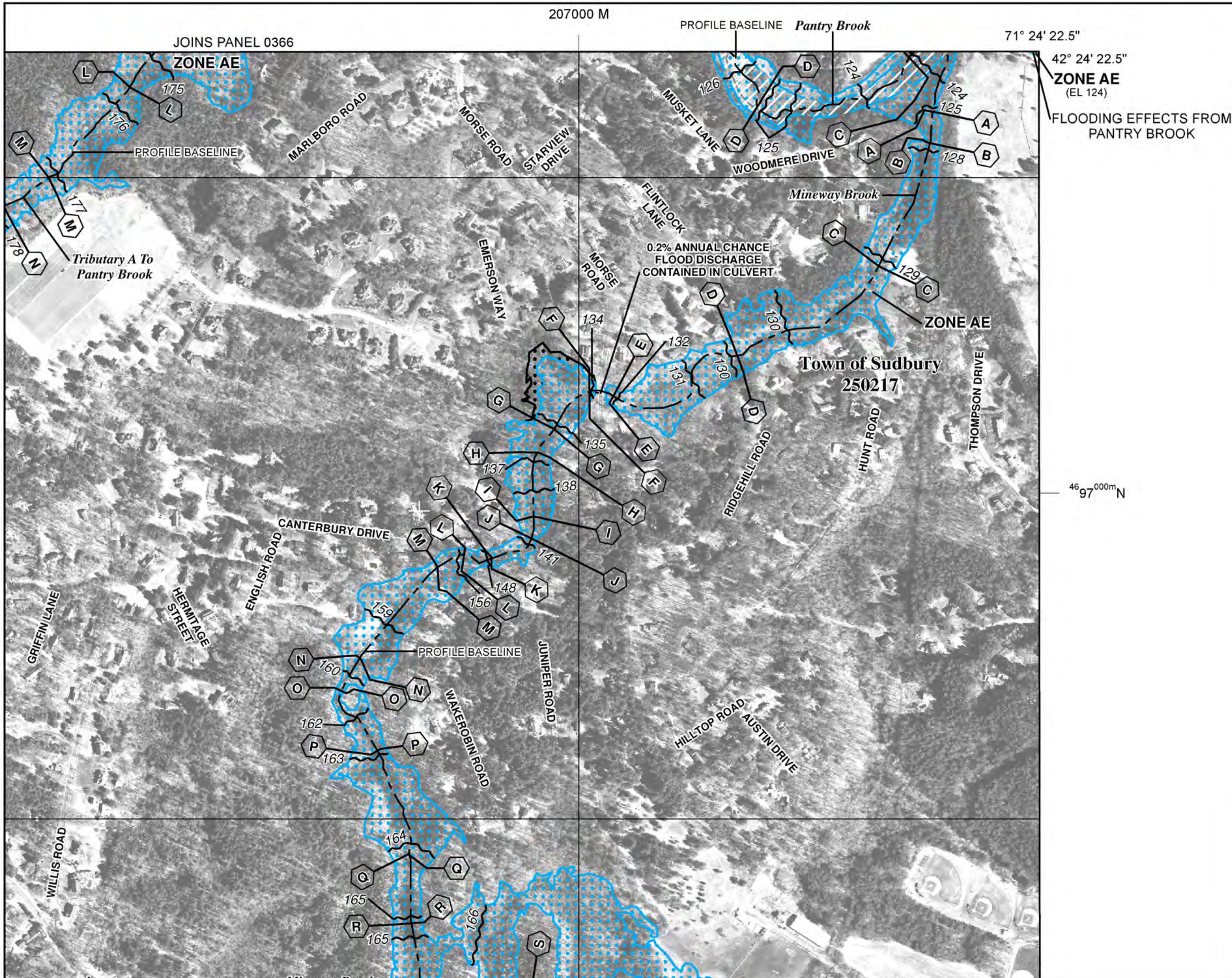
COMMUNITY	NUMBER	PANEL	SUFFIX
ACTON, TOWN OF	250176	0366	F
CONCORD, TOWN OF	250189	0366	F
MAYNARD, TOWN OF	250204	0366	F
SUDBURY, TOWN OF	250217	0366	F

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER 25017C0366F

MAP REVISED JULY 7, 2014

Federal Emergency Management Agency



MAP SCALE 1" = 500'

250 0 500 1000 FEET

METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0368F

FIRM

FLOOD INSURANCE RATE MAP

MIDDLESEX COUNTY, MASSACHUSETTS (ALL JURISDICTIONS)

PANEL 368 OF 656

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
SUDBURY, TOWN OF	250217	0368	F

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER 25017C0368F

MAP REVISED JULY 7, 2014

Federal Emergency Management Agency

FLOODING SOURCE		FLOODWAY			BASE FLOOD WATER-SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
Pantry Brook								
A	7,750[1]	56	105	2.3	121.2	114.7[4]	115.6	0.9
B	9,590[1]	150	585	0.4	123.5	123.5	123.5	0.0
C	10,640[1]	150	252	1.0	123.8	123.8	123.8	0.0
D	11,540[1]	190	232	1.0	124.7	124.7	124.8	0.1
E	12,550[1]	9	29	8.2	131.1	131.1	132.0	0.9
F-O*								
Pearl Hill Brook								
A	2,990[2]	32	106	5.2	320.8	320.8	321.3	0.5
B	3,550[2]	45	91	6.1	328.4	328.4	328.6	0.2
C	4,640[2]	25	71	7.8	335.1	335.1	335.2	0.1
D	7,300[2]	35	84	6.6	349.5	349.5	350.0	0.5
E	9,145[2]	17	65	8.6	364.1	364.1	364.6	0.5
Peppermint Brook								
A	900[3]	31	60	5.0	70.6	65.7[5]	66.1	0.4
B	1,260[3]	78	405	0.7	72.5	72.4	73.4	1.0
C	1,800[3]	70	453	0.7	74.0	73.9	74.7	0.8
D	2,300[3]	63	235	1.3	74.3	74.2	75.2	1.0
E	2,400[3]	117	833	0.4	80.0	80.0	80.7	0.7
F	3,500[3]	40	333	0.9	80.0	80.0	80.7	0.7
G	3,760[3]	11	85	3.4	80.0	80.0	80.7	0.7
H	3,980[3]	69	280	1.0	80.1	80.1	80.8	0.7
I	4,200[3]	20	107	2.7	80.1	80.1	80.8	0.7
J	4,340[3]	33	82	3.0	80.8	80.8	81.3	0.5

[1] Feet above confluence with Sudbury River
[2] Feet above confluence with Walker Brook 2
[3] Feet above confluence with Beaver Brook 3
[4] Elevation computed without consideration of backwater effects from Sudbury River
[5] Elevation computed without consideration of backwater effects from Beaver Brook 3
* No data available

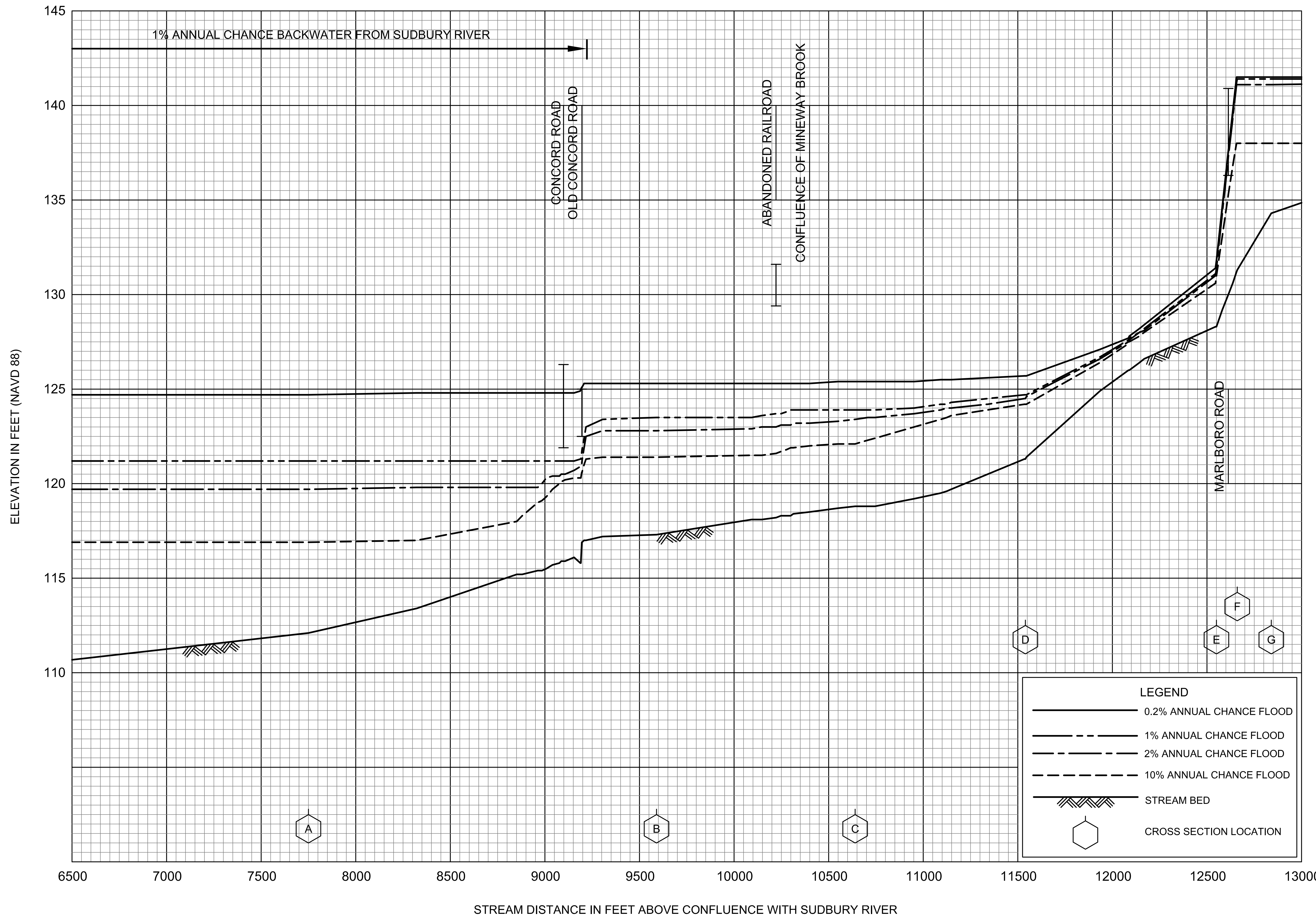
TABLE 12

FEDERAL EMERGENCY MANAGEMENT AGENCY

MIDDLESEX COUNTY, MA
(ALL JURISDICTIONS)

FLOODWAY DATA

PANTRY BROOK – PEARL HILL BROOK – PEPPERMINT BROOK



FLOOD PROFILES

PANTRY BROOK

FEDERAL EMERGENCY MANAGEMENT AGENCY

MIDDLESEX COUNTY, MA

(ALL JURISDICTIONS)

APPENDIX 6.5:

EXISTING HEC-RAS MODEL AND RESULTS

Geometry Plan

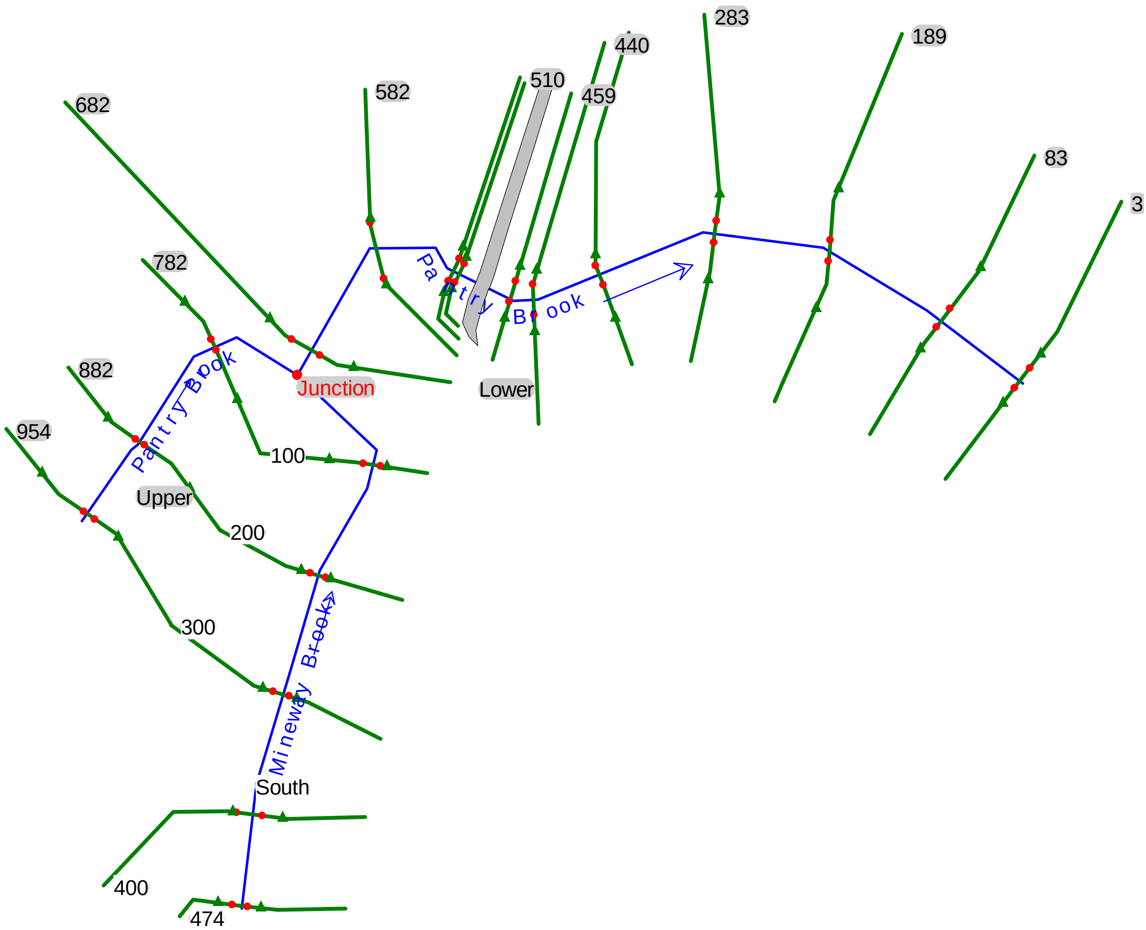
Stream Profile

Stream Cross Sections

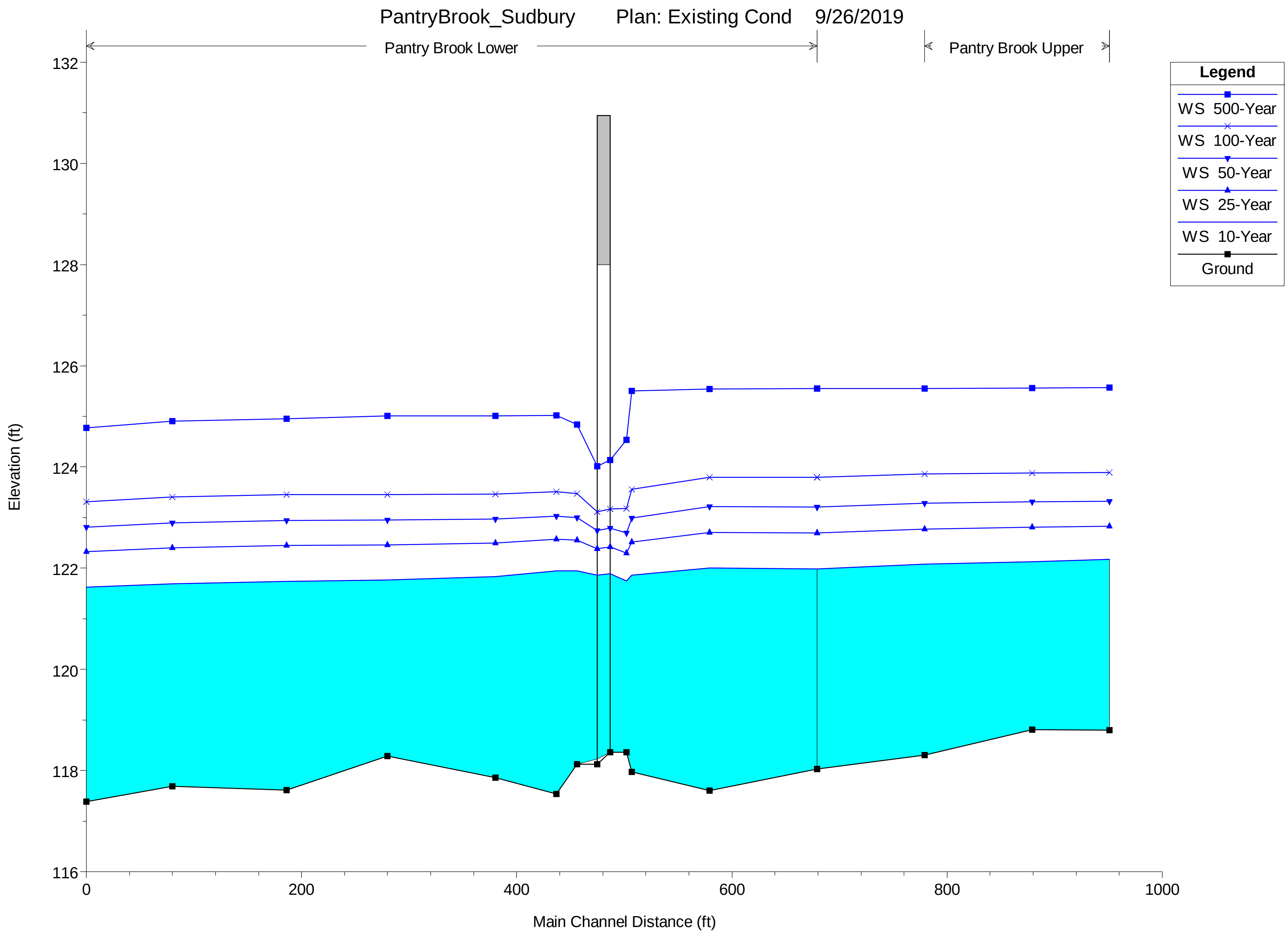
Cross Section Output Table

Detailed Bridge Output

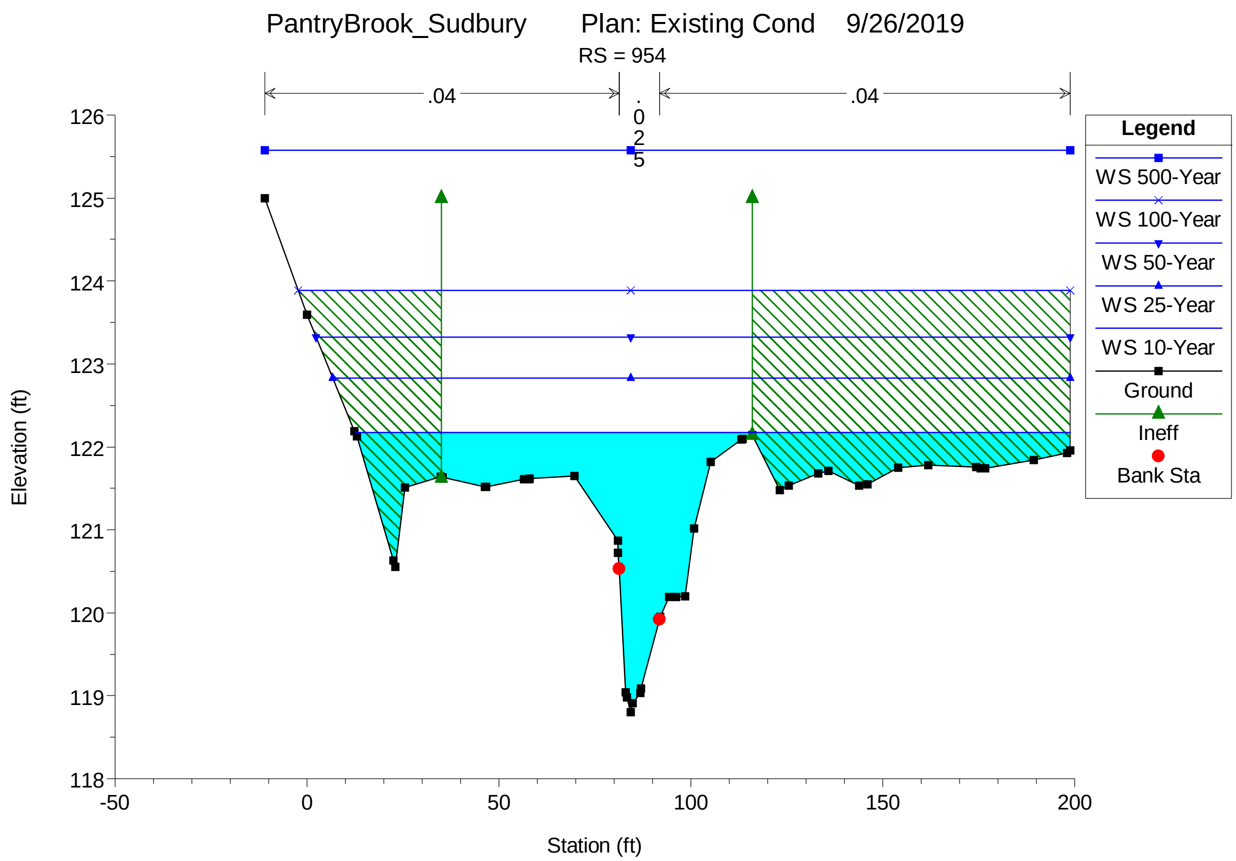
Detailed Output for Cross Section 505
(25-Year and 50-Year Storm Events)

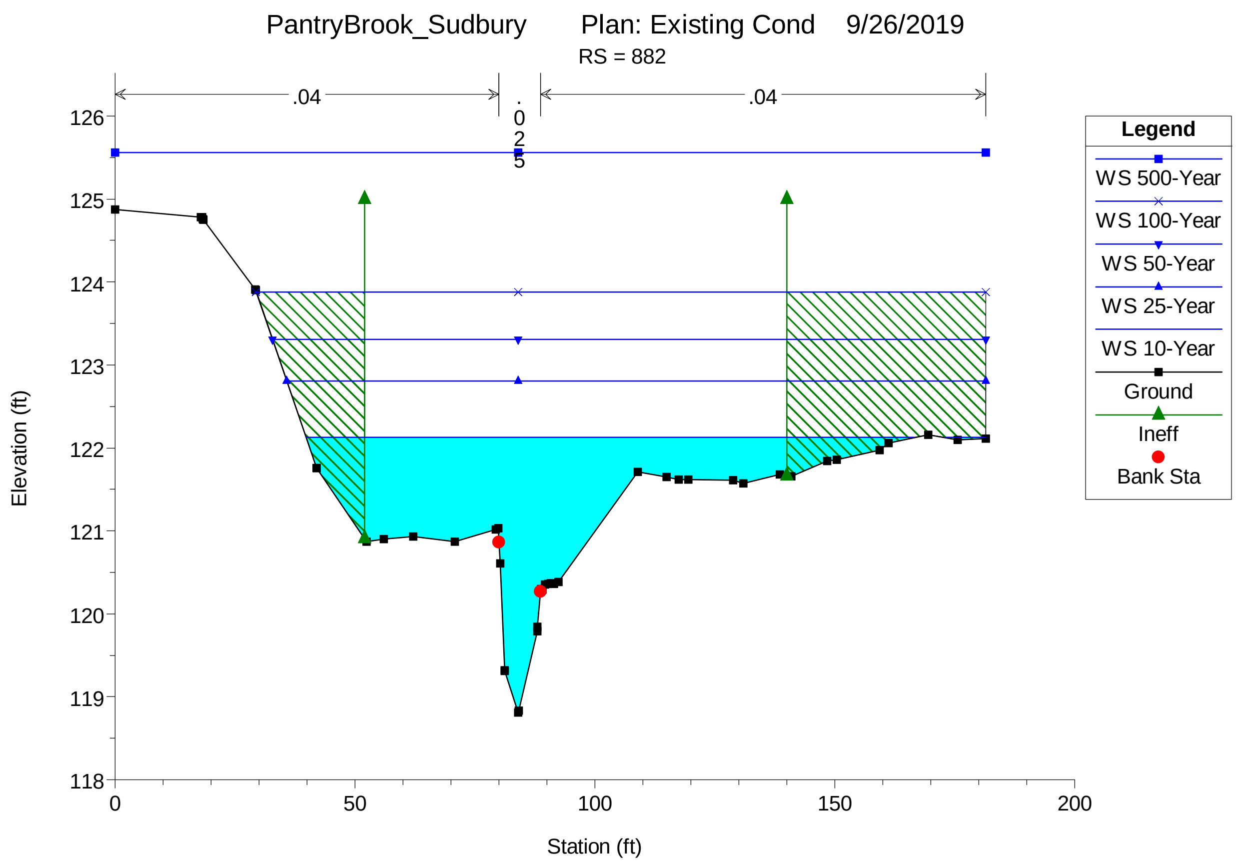


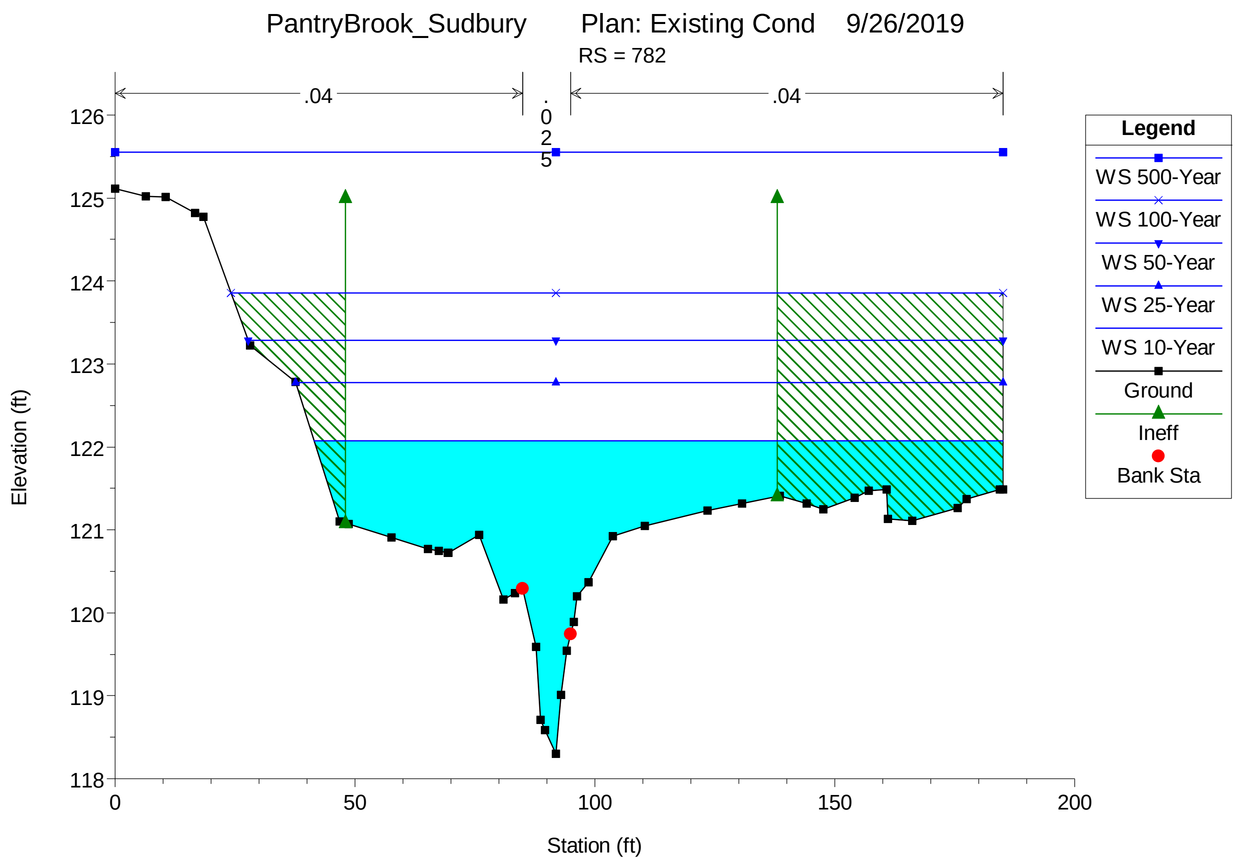
HEC-RAS Geometry Data
E. Princeton Rd over E. Wachusett Brk

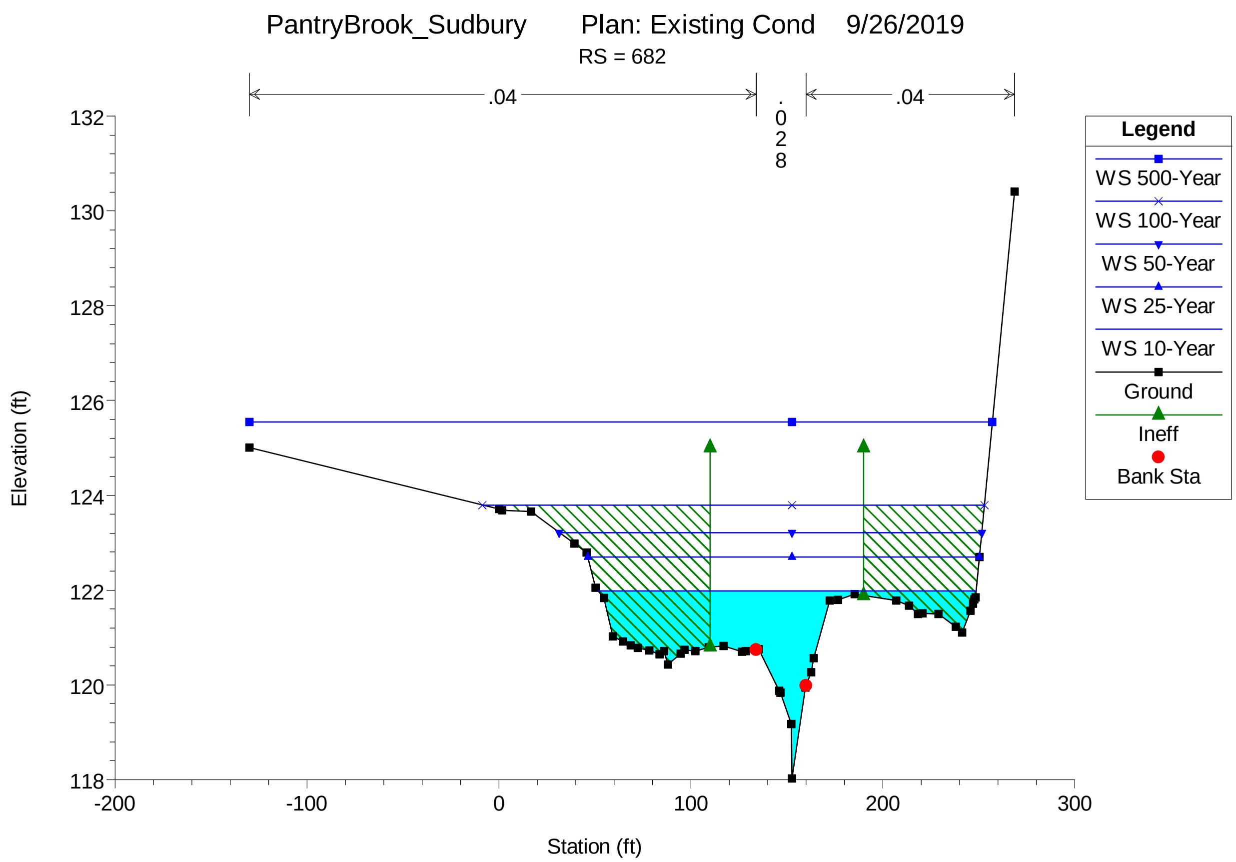


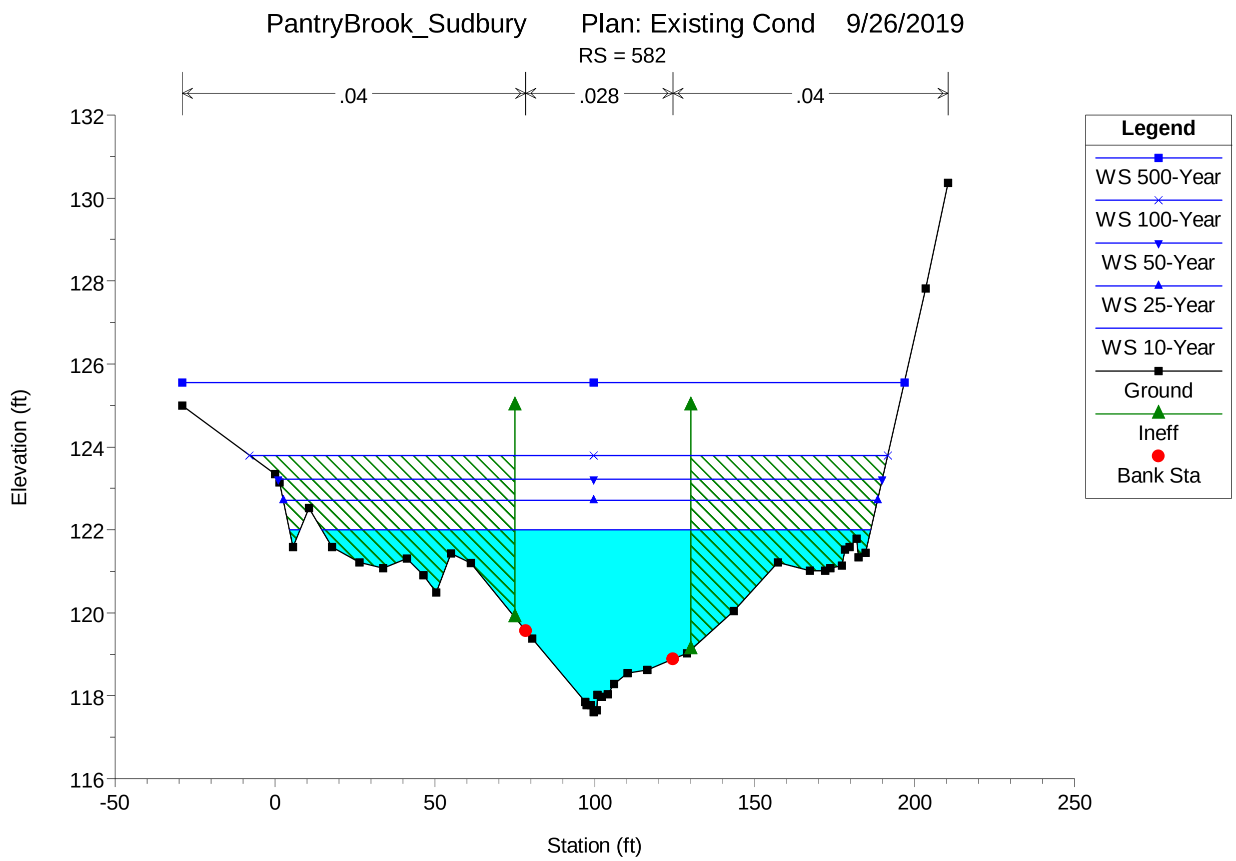
PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
Pantry Brook Lower
Pantry Brook Upper
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Elevation (ft)
116
118
120
122
124
126
128
130
132
0
200
400
600
800
1000
Main Channel Distance (ft)

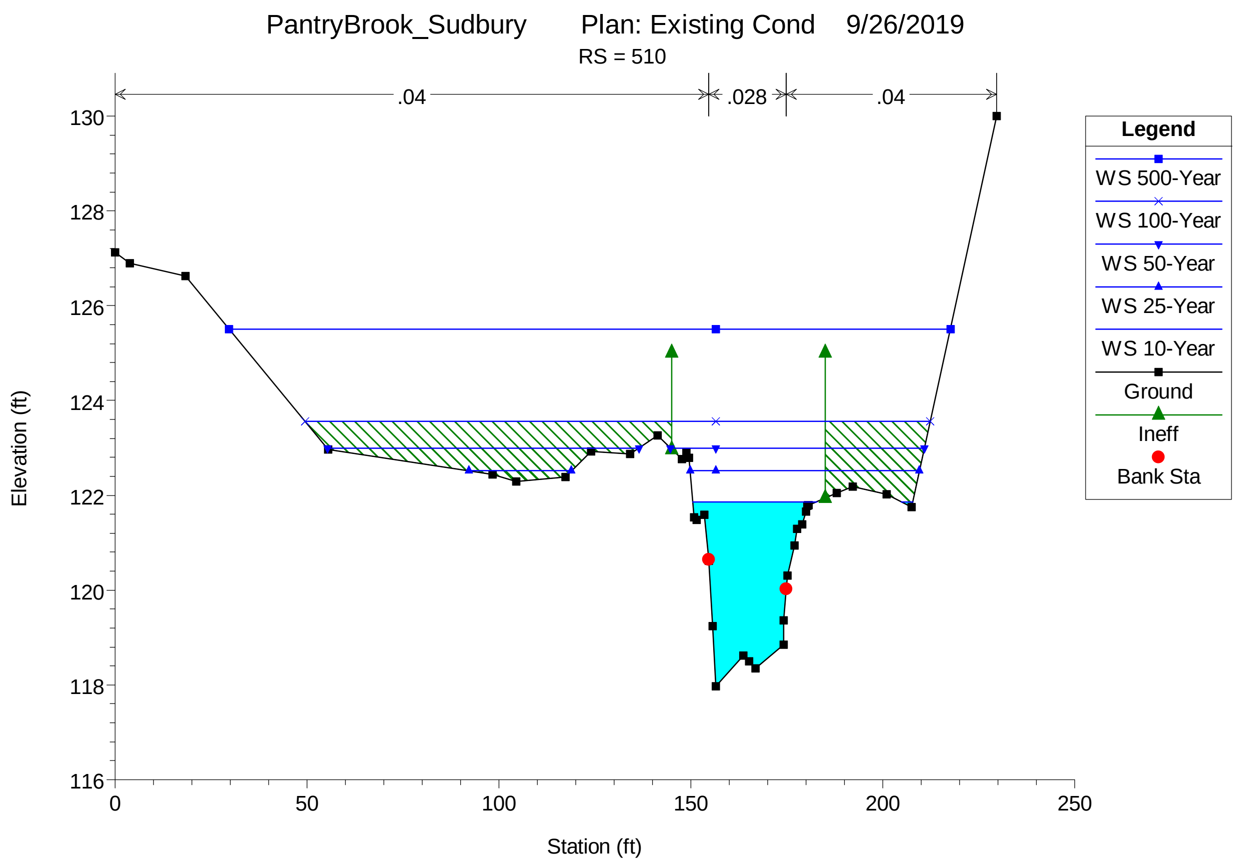

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 954
.04
.025
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
126
125
124
123
122
121
120
119
118
-50
0
50
100
150
200
Station (ft)

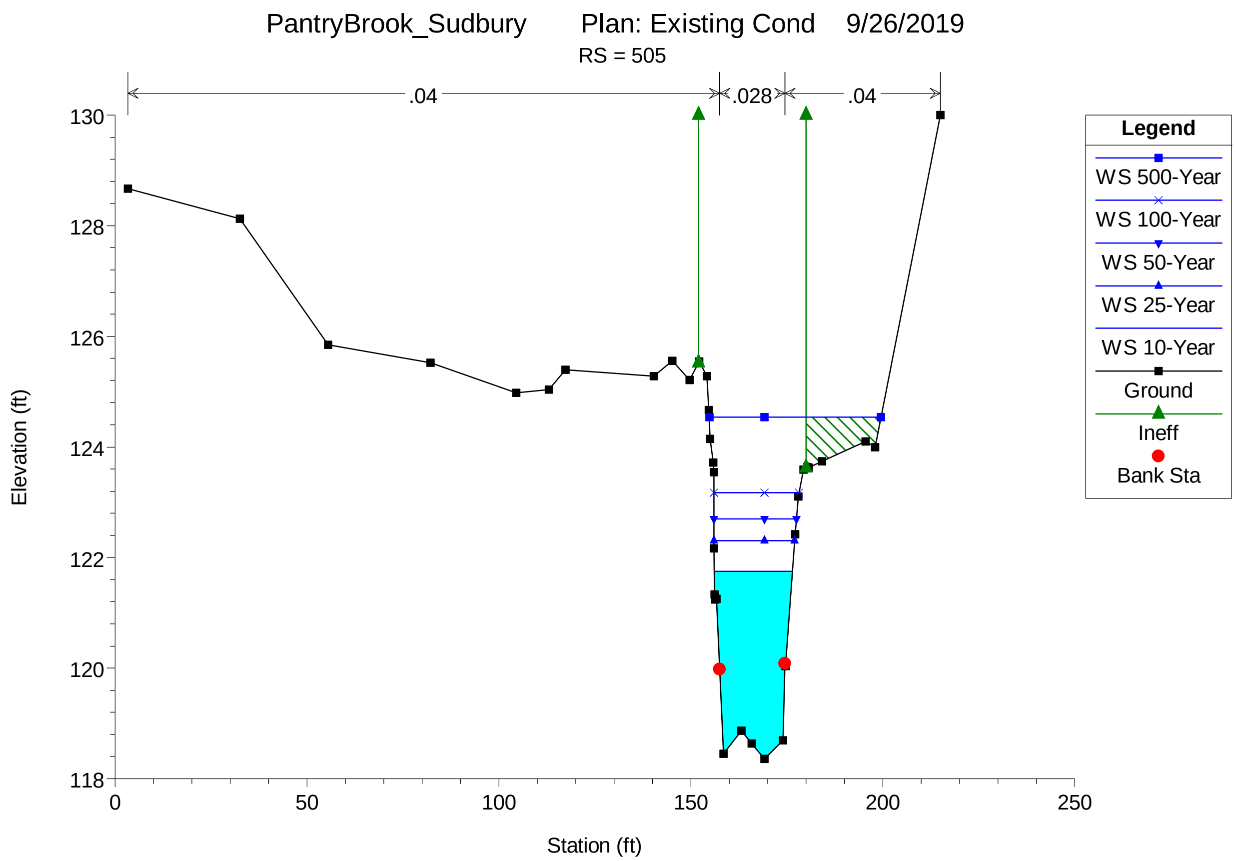

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 882
.04
.025
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
126
125
124
123
122
121
120
119
118
0
50
100
150
200
Station (ft)

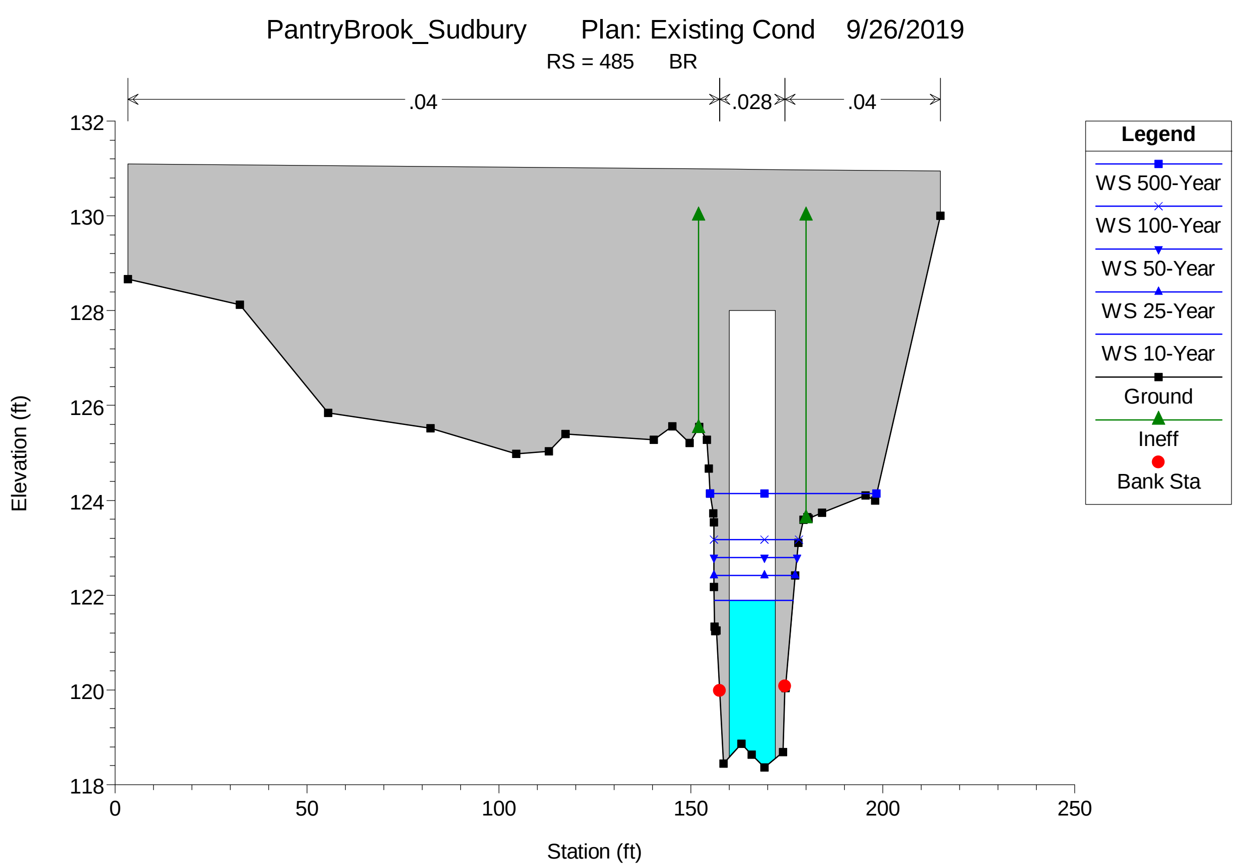

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 782
.04
.025
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
126
125
124
123
122
121
120
119
118
0
50
100
150
200

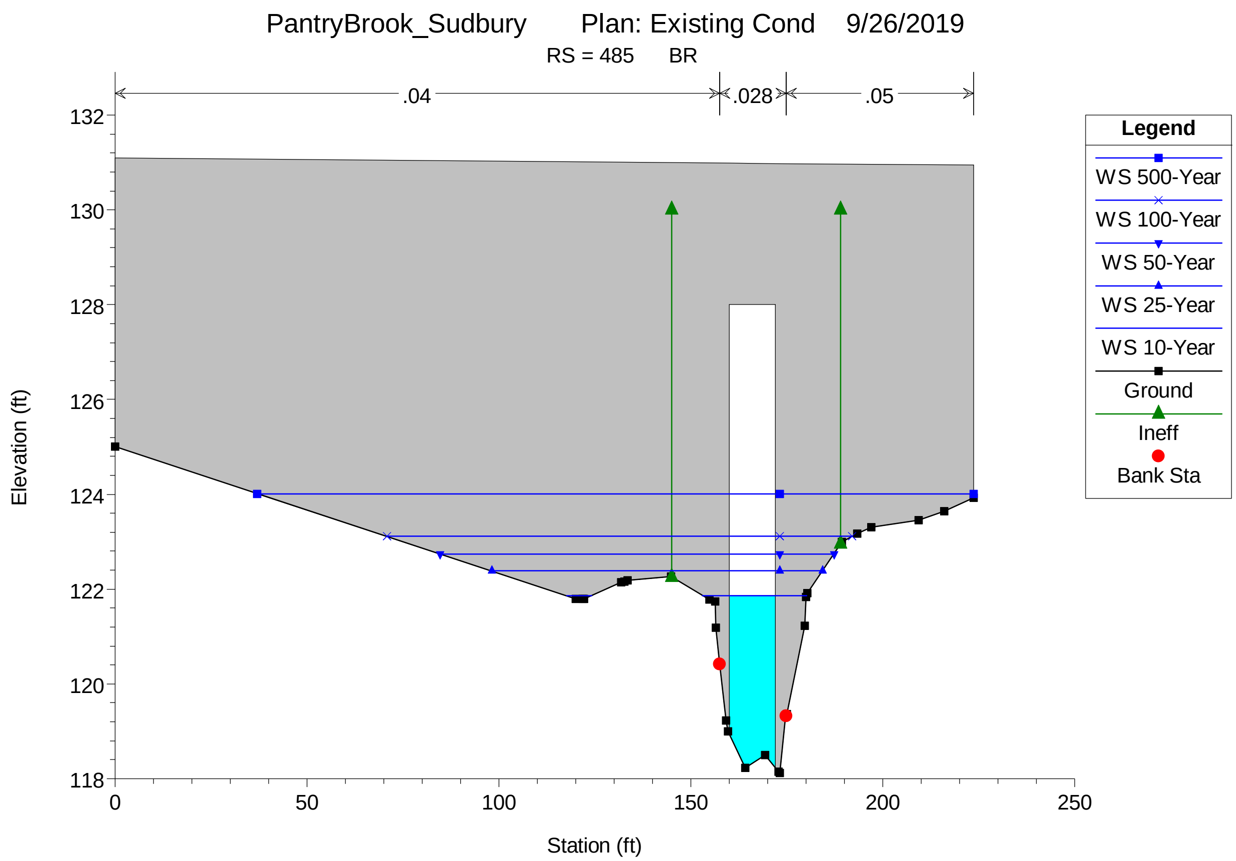

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 682
.04
.028
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
132
130
128
126
124
122
120
118
-200
-100
0
100
200
300

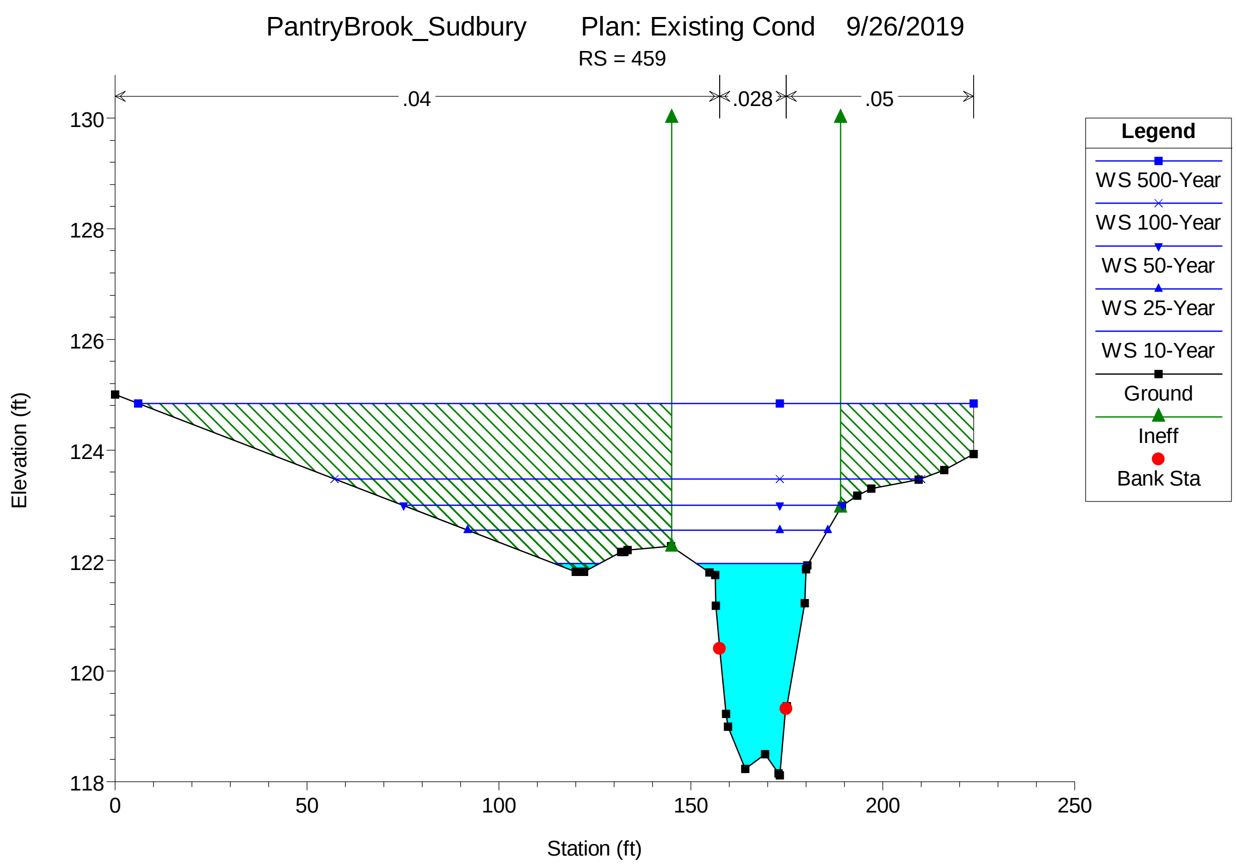

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 582
.04
.028
.04
Elevation (ft)
Station (ft)
132
130
128
126
124
122
120
118
116
-50
0
50
100
150
200
250
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta

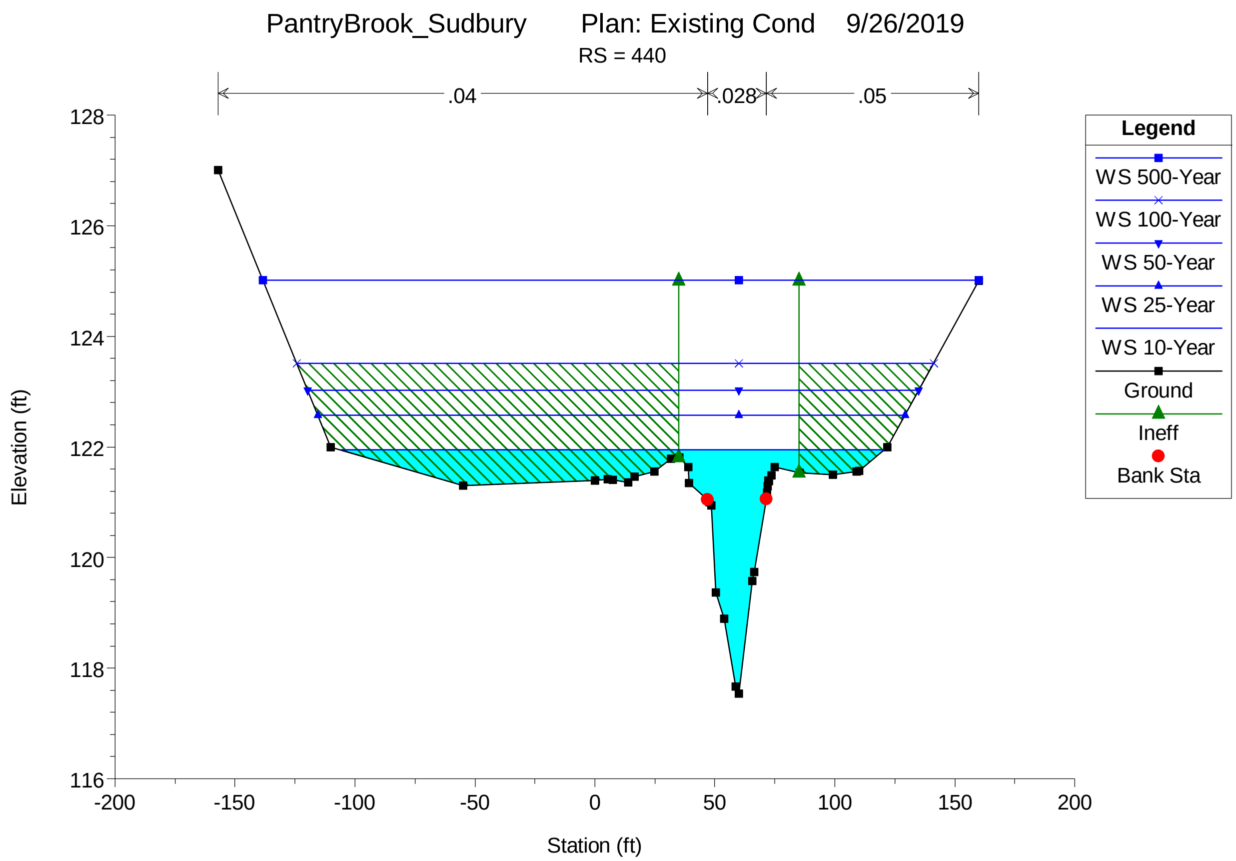

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 510
.04
.028
.04
Elevation (ft)
Station (ft)
130
128
126
124
122
120
118
116
0
50
100
150
200
250
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta

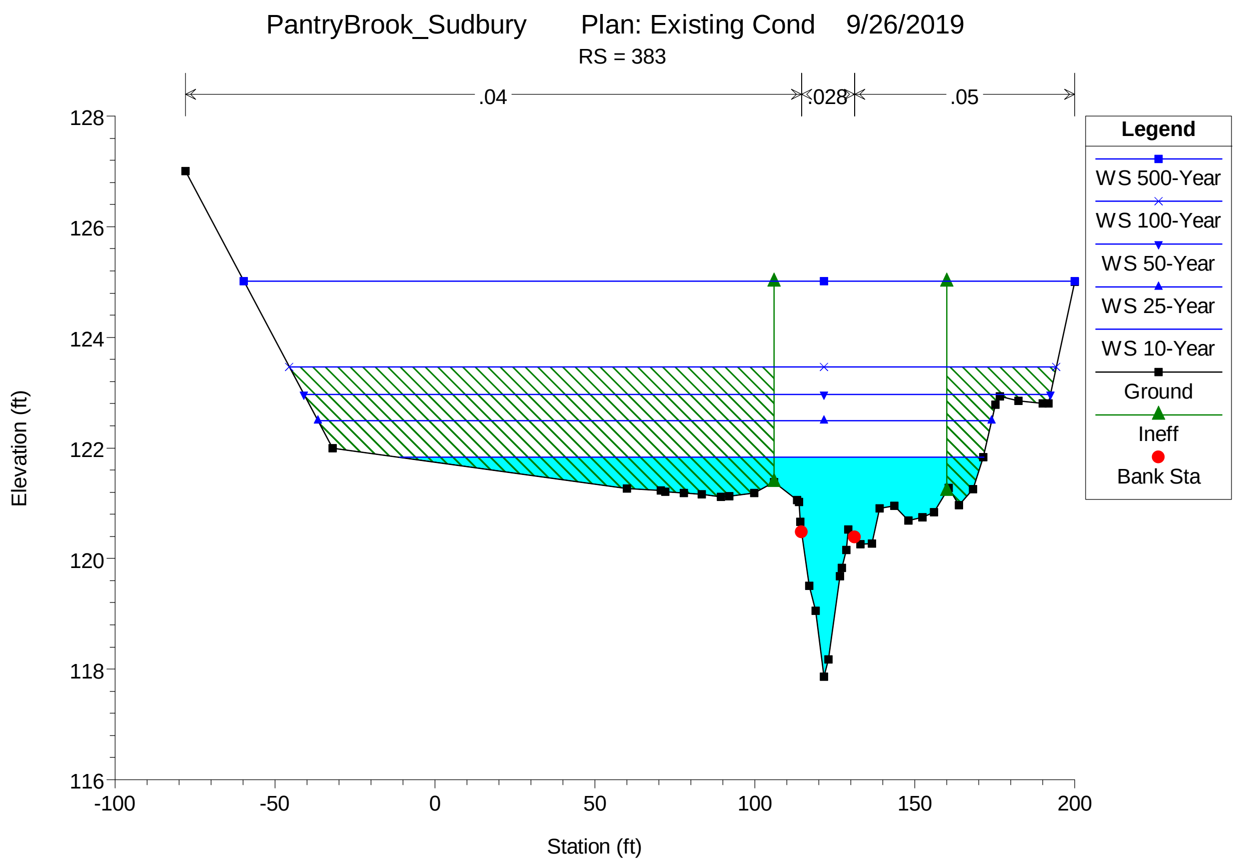

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 505
.04
.028
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
130
128
126
124
122
120
118
0
50
100
150
200
250
Station (ft)

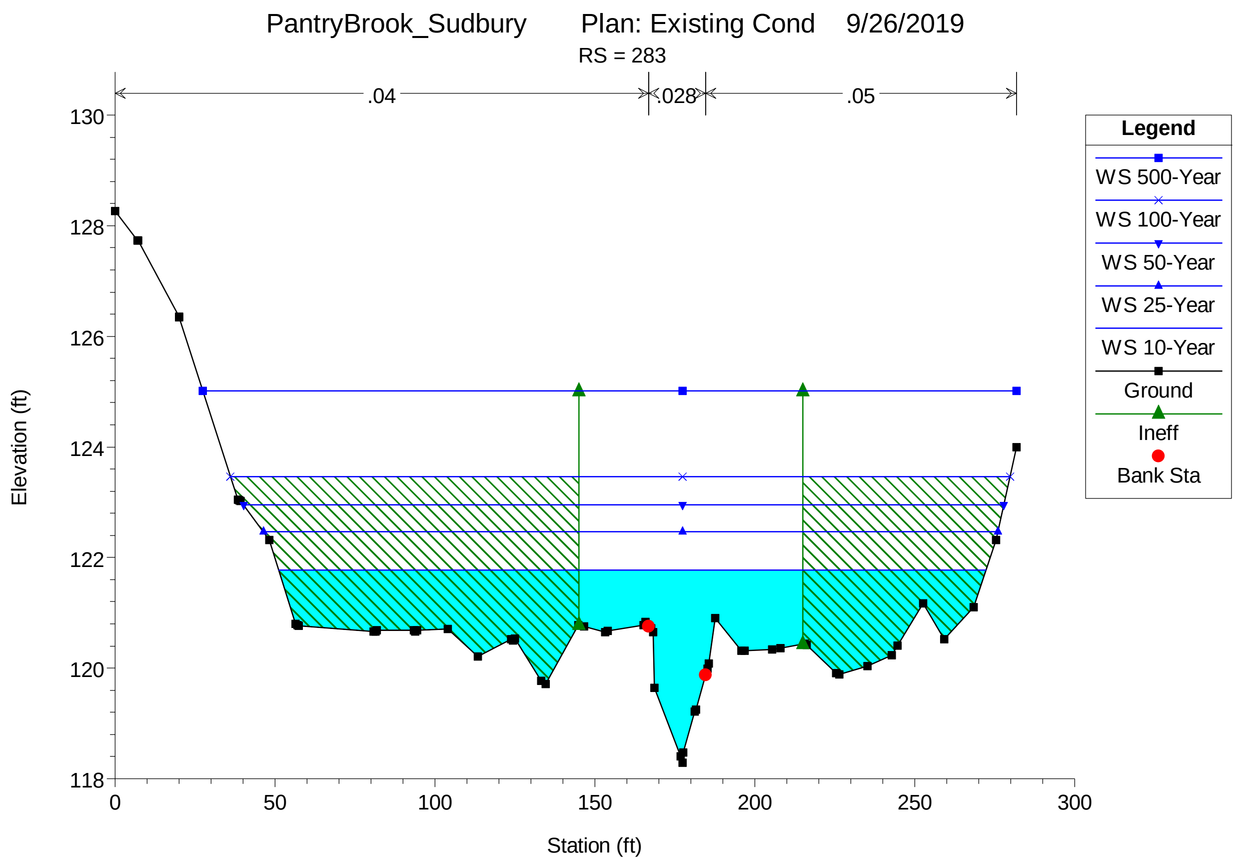

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 485 BR
.04
.028
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
132
130
128
126
124
122
120
118
0
50
100
150
200
250
Station (ft)

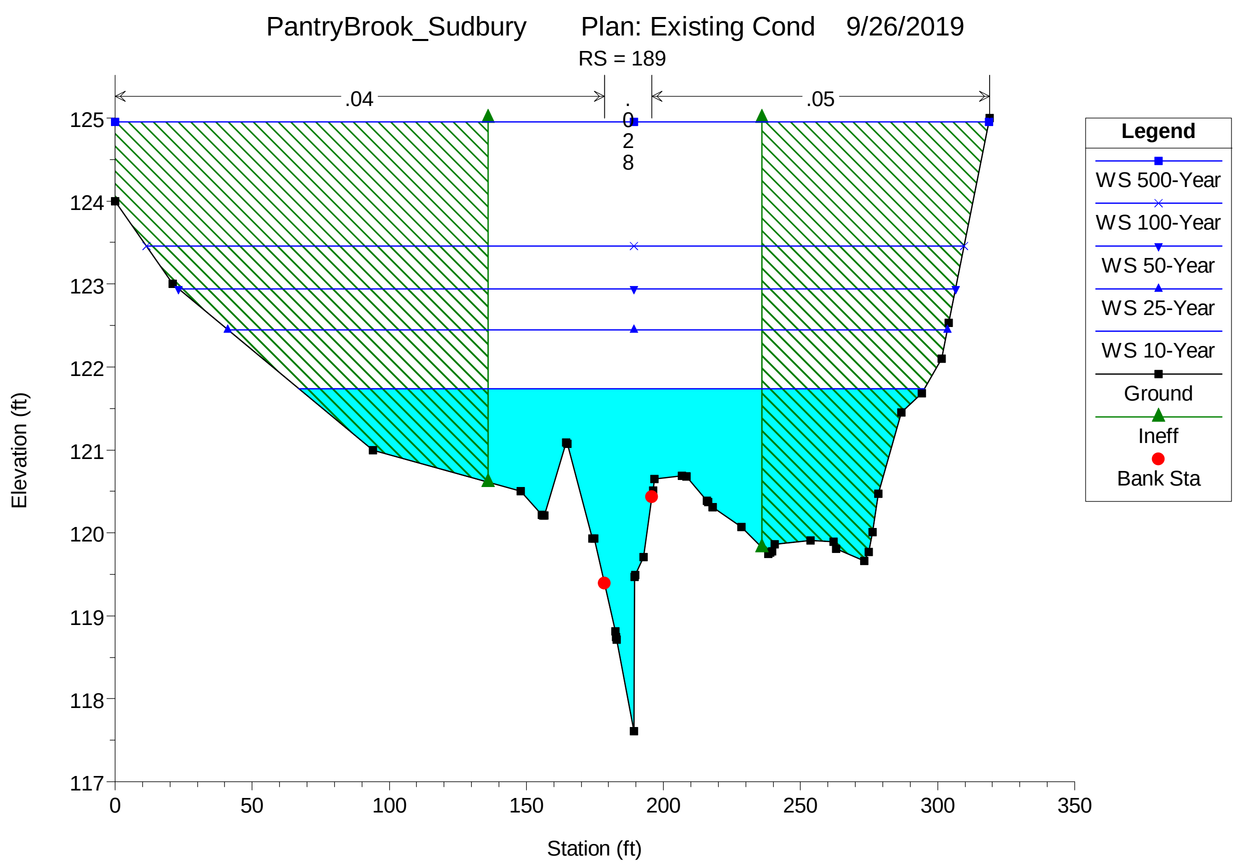

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 485 BR
.04
.028
.05
Elevation (ft)
Station (ft)
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta

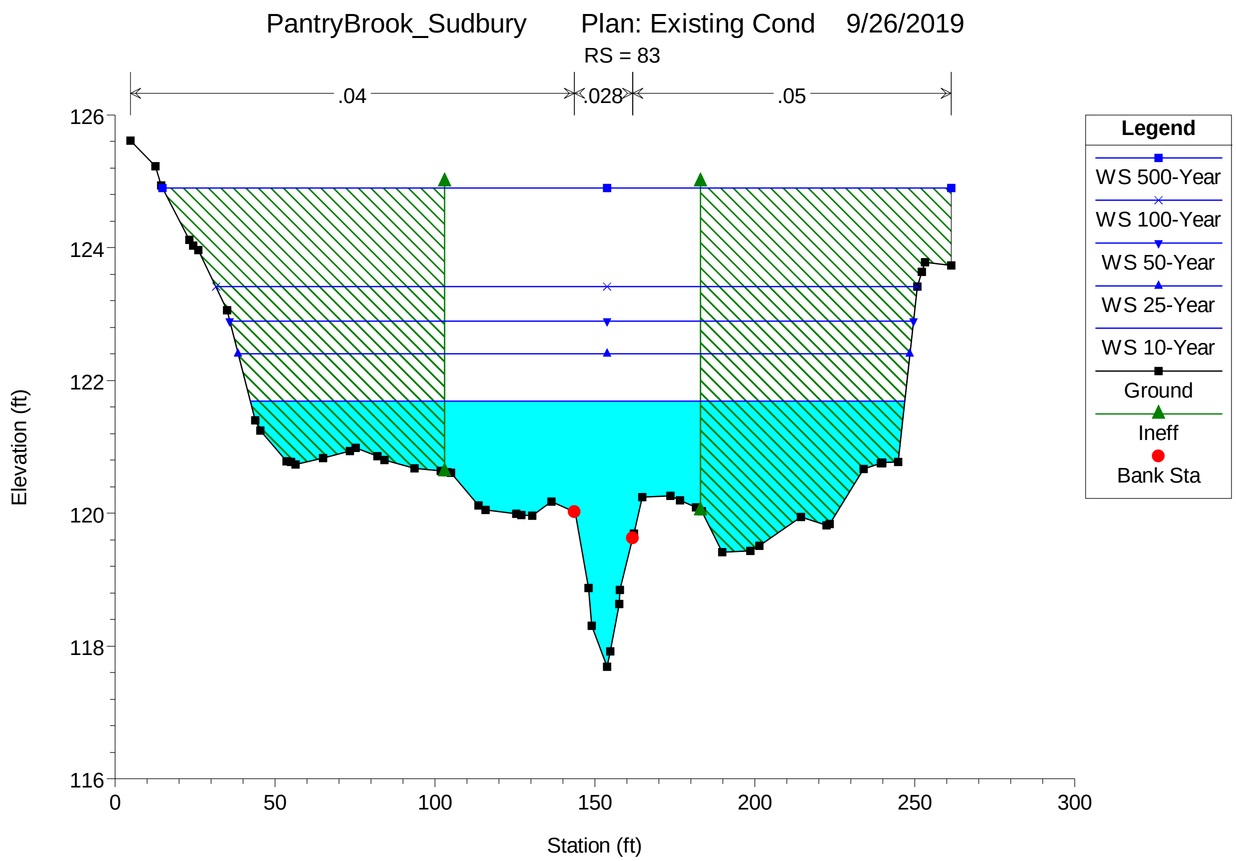

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 459
.04
.028
.05
Elevation (ft)
Station (ft)
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta

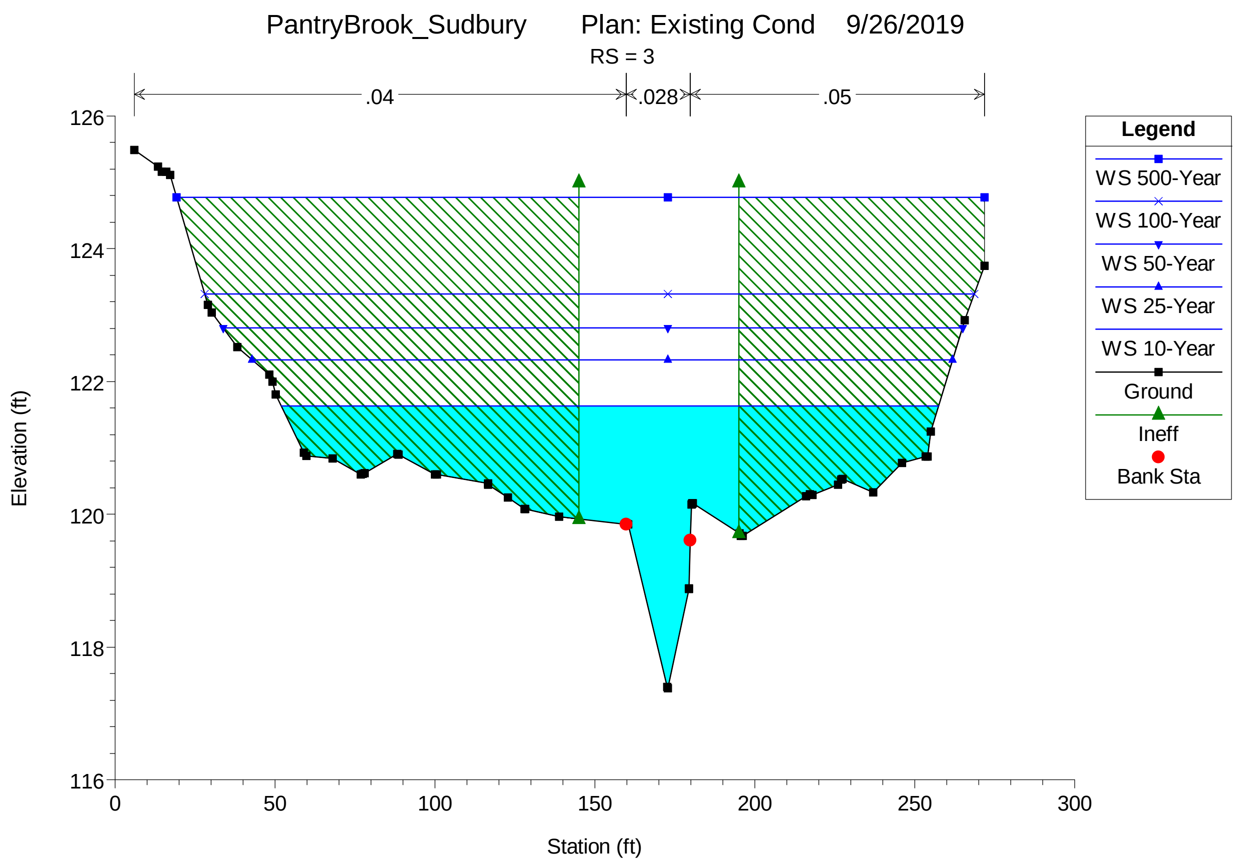

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 440
.04
.028
.05
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
128
126
124
122
120
118
116
-200
-150
-100
-50
0
50
100
150
200

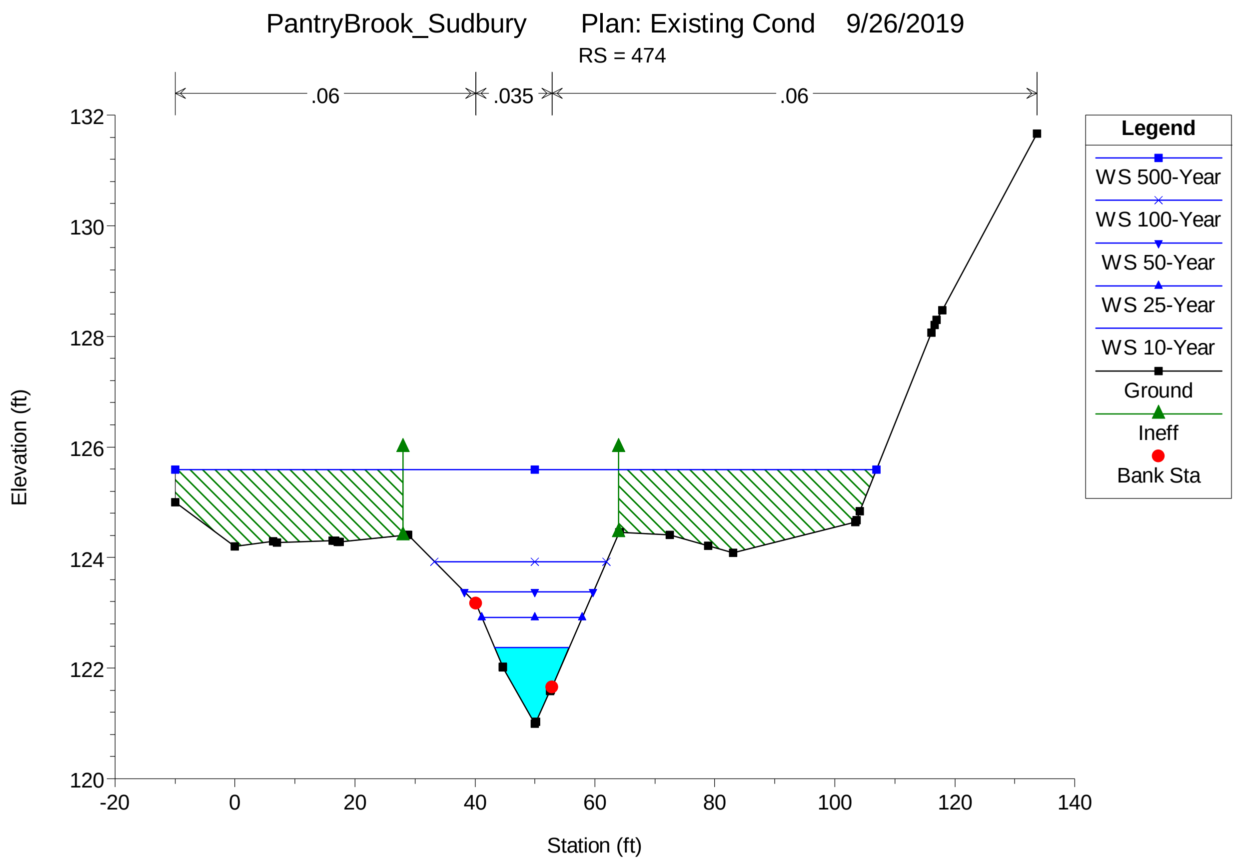

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 383
.04
.028
.05
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
128
126
124
122
120
118
116
-100
-50
0
50
100
150
200

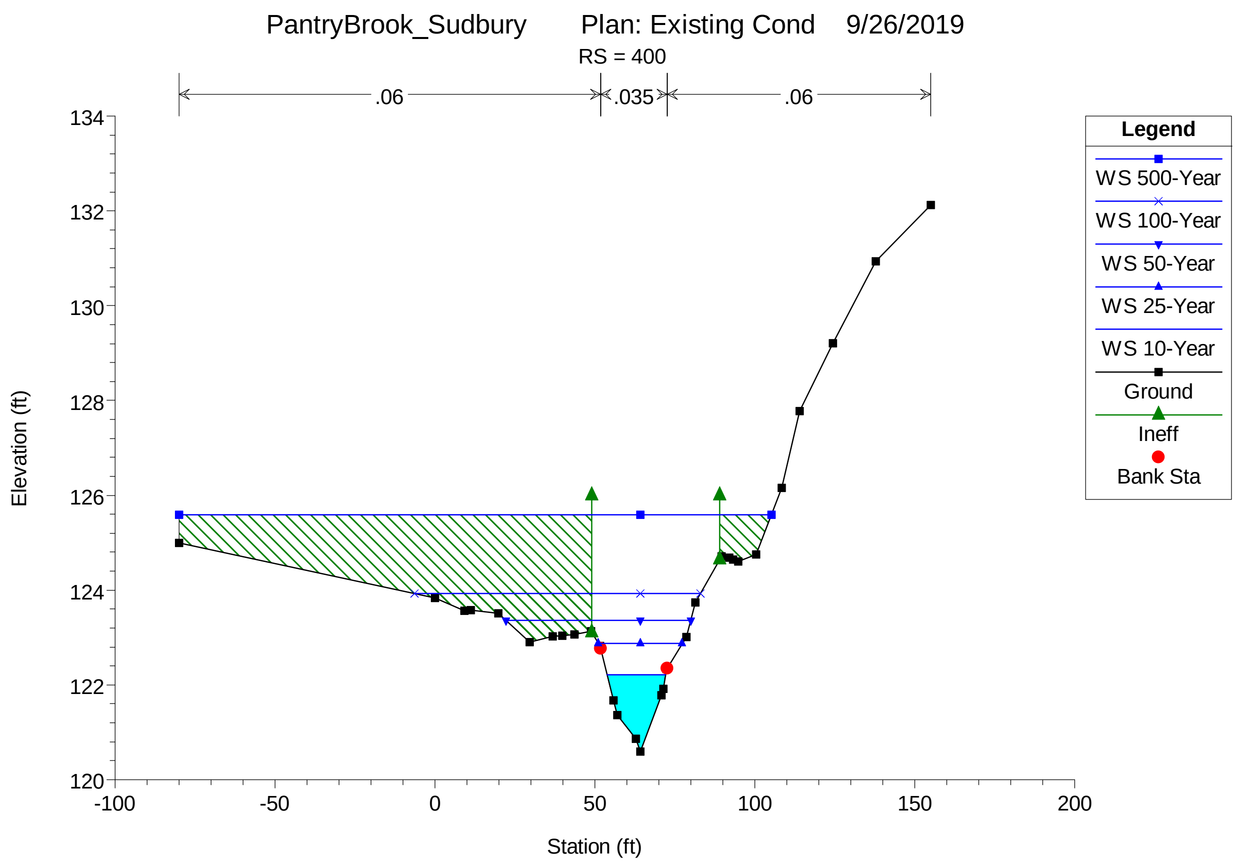

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 283
.04
.028
.05
Elevation (ft)
Station (ft)
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta

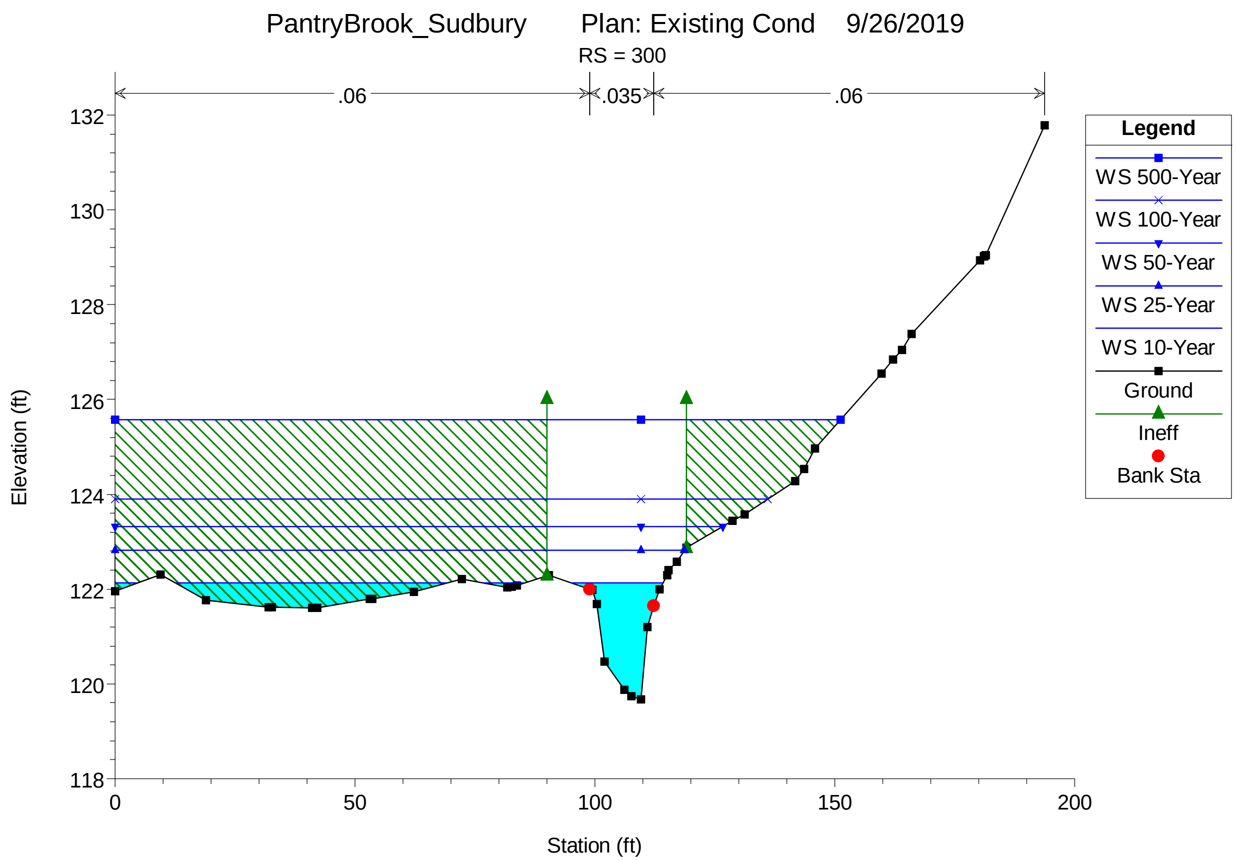

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 189
.04
.028
.05
Elevation (ft)
Station (ft)
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta

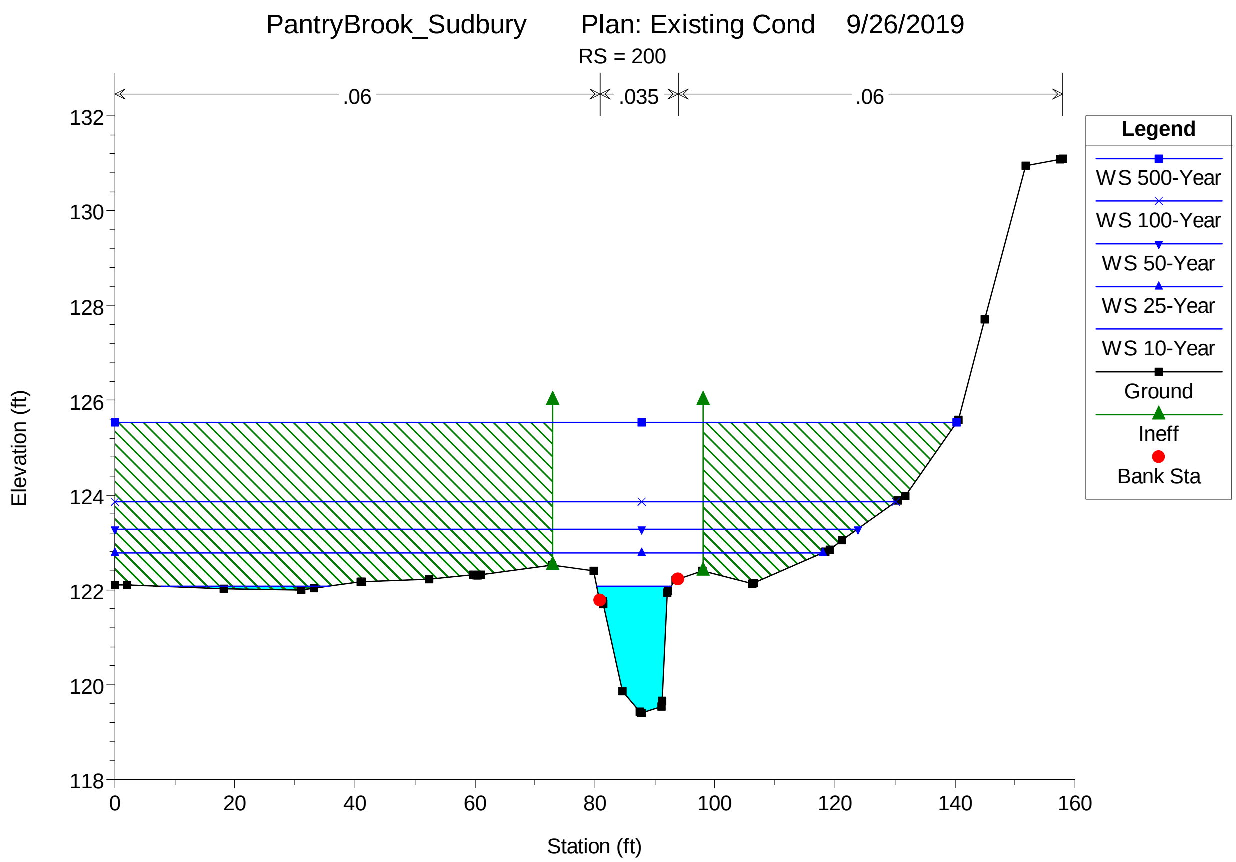

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 83
.04
.028
.05
Elevation (ft)
Station (ft)
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta

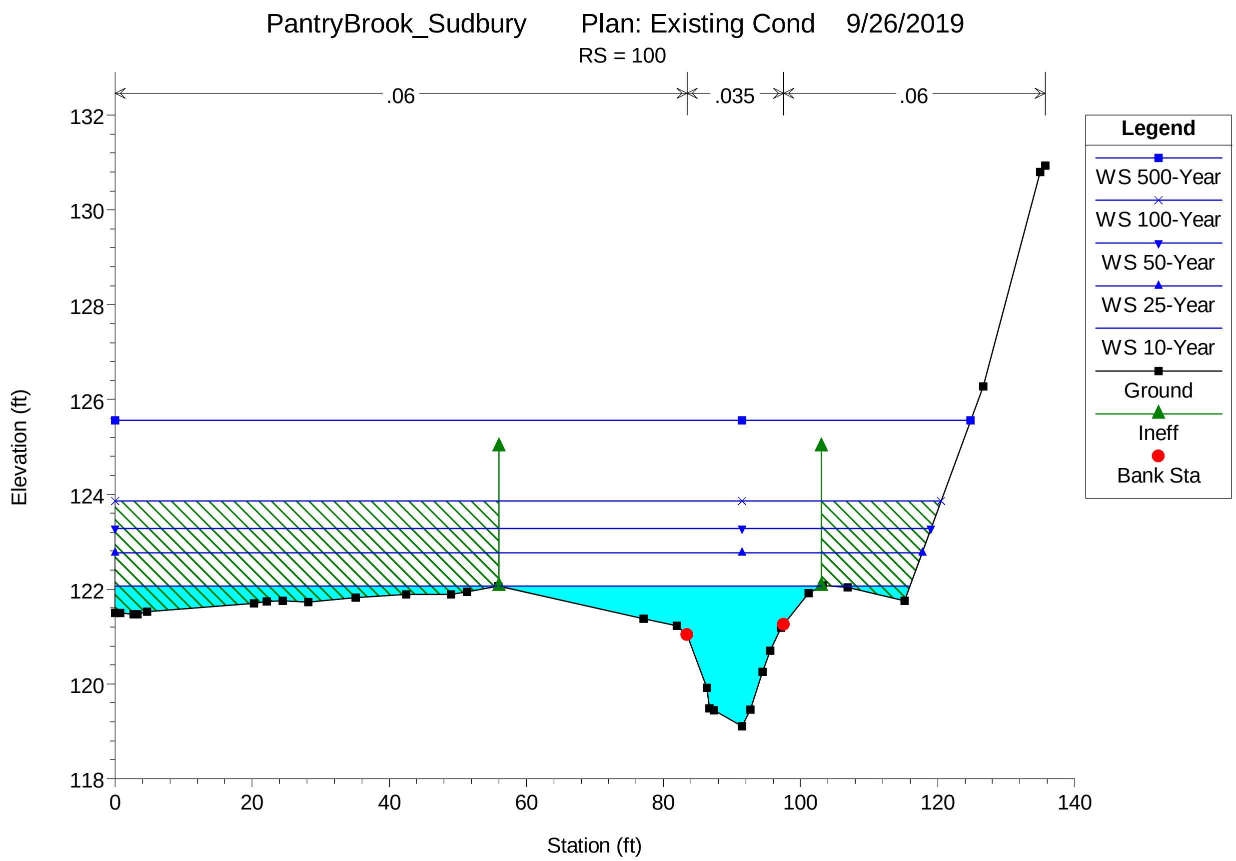

PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 3
.04
.028
.05
Elevation (ft)
Station (ft)
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta


PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 474
.06
.035
.06
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
132
130
128
126
124
122
120
-20
0
20
40
60
80
100
120
140
Station (ft)


PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 400
.06
.035
.06
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
134
132
130
128
126
124
122
120
-100
-50
0
50
100
150
200
Station (ft)


PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 300
.06
.035
.06
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
118
120
122
124
126
128
130
132
0
50
100
150
200


PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 200
.06
.035
.06
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
118
120
122
124
126
128
130
132
0
20
40
60
80
100
120
140
160


PantryBrook_Sudbury Plan: Existing Cond 9/26/2019
RS = 100
.06
.035
.06
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
132
130
128
126
124
122
120
118
0
20
40
60
80
100
120
140
Station (ft)

HEC-RAS Plan: Exist

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Upper	954	10-Year	176.00	118.80	122.17	121.29	122.32	0.001056	3.71	83.14	186.20	0.39
Upper	954	25-Year	259.00	118.80	122.83	121.92	122.94	0.000702	3.48	136.39	192.06	0.33
Upper	954	50-Year	324.00	118.80	123.32	122.14	123.41	0.000541	3.33	176.26	196.42	0.29
Upper	954	100-Year	398.00	118.80	123.89	122.33	123.97	0.000414	3.19	222.20	201.13	0.26
Upper	954	500-Year	640.00	118.80	125.57	122.78	125.58	0.000062	1.52	817.23	209.79	0.11
Upper	882	10-Year	176.00	118.81	122.12	121.54	122.23	0.001075	3.52	97.10	135.00	0.38
Upper	882	25-Year	259.00	118.81	122.81	121.87	122.88	0.000621	3.10	157.30	145.71	0.30
Upper	882	50-Year	324.00	118.81	123.31	122.02	123.37	0.000465	2.94	201.26	148.67	0.26
Upper	882	100-Year	398.00	118.81	123.88	122.17	123.93	0.000352	2.80	251.62	152.06	0.23
Upper	882	500-Year	640.00	118.81	125.56	122.55	125.58	0.000099	1.84	651.82	181.46	0.13
Upper	782	10-Year	176.00	118.30	122.08	121.30	122.14	0.000576	2.75	122.51	143.62	0.28
Upper	782	25-Year	259.00	118.30	122.78	121.57	122.82	0.000379	2.58	185.40	147.44	0.24
Upper	782	50-Year	324.00	118.30	123.28	121.71	123.33	0.000304	2.52	230.94	157.33	0.22
Upper	782	100-Year	398.00	118.30	123.86	121.86	123.90	0.000243	2.46	282.93	160.94	0.20
Upper	782	500-Year	640.00	118.30	125.55	122.24	125.57	0.000071	1.63	723.53	185.05	0.11
Lower	682	10-Year	204.00	118.03	121.98	121.04	122.07	0.000857	2.57	103.59	197.02	0.30
Lower	682	25-Year	305.00	118.03	122.70	121.33	122.77	0.000587	2.56	160.73	204.26	0.26
Lower	682	50-Year	385.00	118.03	123.21	121.52	123.29	0.000479	2.58	201.73	220.20	0.24
Lower	682	100-Year	476.00	118.03	123.80	121.71	123.87	0.000388	2.57	248.44	261.62	0.23
Lower	682	500-Year	783.00	118.03	125.55	122.29	125.56	0.000047	1.14	1184.85	387.15	0.08
Lower	582	10-Year	204.00	117.60	122.01	119.35	122.03	0.000092	1.16	185.22	175.13	0.11
Lower	582	25-Year	305.00	117.60	122.71	119.61	122.74	0.000110	1.44	223.84	185.71	0.12
Lower	582	50-Year	385.00	117.60	123.22	119.79	123.25	0.000119	1.62	251.69	188.93	0.13
Lower	582	100-Year	476.00	117.60	123.79	119.99	123.84	0.000122	1.77	283.51	199.50	0.14
Lower	582	500-Year	783.00	117.60	125.54	120.52	125.56	0.000035	1.14	1029.63	225.73	0.08
Lower	510	10-Year	204.00	117.97	121.87	120.03	122.00	0.000743	2.99	72.73	35.36	0.29
Lower	510	25-Year	305.00	117.97	122.52	120.50	122.71	0.000847	3.60	95.32	86.45	0.32
Lower	510	50-Year	385.00	117.97	122.99	120.83	123.22	0.000869	3.94	112.87	147.37	0.33
Lower	510	100-Year	476.00	117.97	123.56	121.19	123.80	0.000828	4.16	135.47	162.86	0.33
Lower	510	500-Year	783.00	117.97	125.50	122.33	125.55	0.000174	2.38	594.44	187.88	0.16
Lower	505	10-Year	204.00	118.36	121.74	120.31	121.97	0.001328	3.83	55.42	20.35	0.38
Lower	505	25-Year	305.00	118.36	122.30	120.83	122.65	0.001679	4.81	66.94	21.09	0.44
Lower	505	50-Year	385.00	118.36	122.70	121.19	123.14	0.001867	5.43	75.39	21.53	0.48
Lower	505	100-Year	476.00	118.36	123.18	121.59	123.71	0.001929	5.95	85.85	22.21	0.49
Lower	505	500-Year	783.00	118.36	124.54	122.71	125.32	0.002052	7.32	118.76	44.75	0.53
Lower	485		Bridge									
Lower	459	10-Year	204.00	118.12	121.94	120.25	122.11	0.000860	3.35	67.75	40.99	0.32
Lower	459	25-Year	305.00	118.12	122.55	120.75	122.79	0.001024	4.09	89.91	93.83	0.36
Lower	459	50-Year	385.00	118.12	123.00	121.11	123.27	0.001061	4.47	108.89	114.36	0.38
Lower	459	100-Year	476.00	118.12	123.48	121.49	123.78	0.001056	4.78	129.98	152.81	0.38
Lower	459	500-Year	783.00	118.12	124.84	122.72	125.23	0.001030	5.56	189.92	217.55	0.39
Lower	440	10-Year	204.00	117.54	121.95	120.33	122.08	0.000868	2.94	78.80	226.35	0.31
Lower	440	25-Year	305.00	117.54	122.57	120.85	122.73	0.000857	3.36	110.07	244.63	0.32
Lower	440	50-Year	385.00	117.54	123.03	121.22	123.21	0.000822	3.58	132.93	254.71	0.32
Lower	440	100-Year	476.00	117.54	123.52	121.61	123.71	0.000781	3.78	157.26	265.45	0.32
Lower	440	500-Year	783.00	117.54	125.02	122.49	125.04	0.000081	1.48	969.67	298.39	0.11
Lower	383	10-Year	204.00	117.86	121.83	121.11	122.01	0.001612	3.78	78.88	182.41	0.42
Lower	383	25-Year	305.00	117.86	122.50	121.53	122.67	0.001288	3.95	114.79	210.64	0.39
Lower	383	50-Year	385.00	117.86	122.97	121.76	123.15	0.001138	4.08	140.39	233.27	0.38
Lower	383	100-Year	476.00	117.86	123.47	121.99	123.66	0.001024	4.21	167.29	239.73	0.37
Lower	383	500-Year	783.00	117.86	125.01	122.62	125.03	0.000102	1.64	877.57	259.72	0.12
Lower	283	10-Year	204.00	118.29	121.77	120.95	121.86	0.000925	2.92	109.11	221.09	0.32
Lower	283	25-Year	305.00	118.29	122.46	121.25	122.55	0.000704	2.99	157.70	229.61	0.29
Lower	283	50-Year	385.00	118.29	122.95	121.43	123.04	0.000617	3.07	191.77	237.69	0.28
Lower	283	100-Year	476.00	118.29	123.46	121.62	123.55	0.000555	3.17	227.36	243.73	0.27
Lower	283	500-Year	783.00	118.29	125.01	122.13	125.02	0.000056	1.24	1076.02	254.38	0.09
Lower	189	10-Year	204.00	117.61	121.74	120.69	121.78	0.000495	2.15	158.06	228.27	0.23
Lower	189	25-Year	305.00	117.61	122.45	120.97	122.49	0.000366	2.16	229.04	262.55	0.21
Lower	189	50-Year	385.00	117.61	122.94	121.15	122.99	0.000318	2.20	278.41	283.54	0.20
Lower	189	100-Year	476.00	117.61	123.46	121.29	123.50	0.000285	2.26	329.85	298.32	0.19
Lower	189	500-Year	783.00	117.61	124.95	121.71	125.01	0.000232	2.48	479.49	318.72	0.18
Lower	83	10-Year	204.00	117.69	121.69	120.46	121.74	0.000392	2.13	149.77	204.48	0.22
Lower	83	25-Year	305.00	117.69	122.40	120.76	122.45	0.000334	2.27	206.81	209.95	0.21

HEC-RAS Plan: Exist (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Lower	83	50-Year	385.00	117.69	122.90	120.93	122.95	0.000309	2.37	246.36	213.74	0.20
Lower	83	100-Year	476.00	117.69	123.41	121.11	123.47	0.000291	2.49	287.50	219.21	0.20
Lower	83	500-Year	783.00	117.69	124.90	121.59	124.98	0.000260	2.82	406.92	246.73	0.20
Lower	3	10-Year	204.00	117.38	121.63	120.11	121.70	0.000470	2.40	114.11	205.29	0.24
Lower	3	25-Year	305.00	117.38	122.33	120.51	122.42	0.000470	2.74	149.07	219.08	0.25
Lower	3	50-Year	385.00	117.38	122.81	120.74	122.92	0.000471	2.97	173.29	231.28	0.25
Lower	3	100-Year	476.00	117.38	123.32	120.97	123.43	0.000471	3.20	198.47	240.63	0.26
Lower	3	500-Year	783.00	117.38	124.78	121.60	124.94	0.000471	3.82	271.48	252.54	0.27

HEC-RAS Plan: Exist River: Mineway Brook Reach: South

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
South	474	10-Year	28.00	121.00	122.37	122.17	122.54	0.008838	3.43	8.83	12.41	0.67
South	474	25-Year	46.00	121.00	122.92	122.44	123.06	0.004435	3.08	16.87	16.77	0.50
South	474	50-Year	61.00	121.00	123.38	122.63	123.49	0.002571	2.80	25.48	21.42	0.40
South	474	100-Year	78.00	121.00	123.93	122.81	124.01	0.001386	2.53	39.23	28.63	0.31
South	474	500-Year	143.00	121.00	125.59	123.32	125.64	0.000440	2.11	97.04	116.96	0.19
South	400	10-Year	28.00	120.60	122.21	121.60	122.25	0.001793	1.68	16.71	18.23	0.31
South	400	25-Year	46.00	120.60	122.87	121.82	122.91	0.000823	1.53	31.10	26.17	0.22
South	400	50-Year	61.00	120.60	123.36	121.97	123.39	0.000516	1.47	45.43	57.77	0.19
South	400	100-Year	78.00	120.60	123.92	122.11	123.95	0.000332	1.40	63.58	89.33	0.16
South	400	500-Year	143.00	120.60	125.59	122.56	125.61	0.000165	1.39	128.04	185.15	0.12
South	300	10-Year	28.00	119.67	122.13	120.70	122.16	0.000554	1.29	22.22	89.03	0.18
South	300	25-Year	46.00	119.67	122.82	120.98	122.85	0.000393	1.38	39.98	118.71	0.16
South	300	50-Year	61.00	119.67	123.32	121.18	123.35	0.000316	1.41	54.51	126.68	0.15
South	300	100-Year	78.00	119.67	123.90	121.40	123.92	0.000247	1.41	71.13	135.97	0.14
South	300	500-Year	143.00	119.67	125.57	122.06	125.60	0.000175	1.56	119.59	151.17	0.12
South	200	10-Year	28.00	119.40	122.08	120.36	122.10	0.000482	1.26	22.29	40.60	0.16
South	200	25-Year	46.00	119.40	122.78	120.67	122.81	0.000439	1.43	35.99	117.99	0.16
South	200	50-Year	61.00	119.40	123.28	120.89	123.32	0.000367	1.49	48.67	123.79	0.15
South	200	100-Year	78.00	119.40	123.86	121.11	123.89	0.000295	1.51	63.16	130.18	0.14
South	200	500-Year	143.00	119.40	125.54	121.81	125.58	0.000220	1.69	105.06	140.29	0.13
South	100	10-Year	28.00	119.11	122.06	120.16	122.07	0.000157	0.84	44.04	113.77	0.10
South	100	25-Year	46.00	119.11	122.77	120.46	122.78	0.000116	0.88	77.32	117.74	0.09
South	100	50-Year	61.00	119.11	123.28	120.66	123.29	0.000097	0.90	101.35	119.04	0.09
South	100	100-Year	78.00	119.11	123.87	120.86	123.87	0.000080	0.91	128.73	120.52	0.08
South	100	500-Year	143.00	119.11	125.56	121.50	125.56	0.000018	0.54	484.06	124.83	0.04

Plan: Exist Pantry Brook Lower RS: 485 Profile: 10-Year

E.G. US. (ft)	121.97	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	121.74	E.G. Elev (ft)	122.30	122.25
Q Total (cfs)	204.00	W.S. Elev (ft)	121.89	121.86
Q Bridge (cfs)	204.00	Crit W.S. (ft)	120.69	120.52
Q Weir (cfs)		Max Chl Dpth (ft)	3.53	3.63
Weir Sta Lft (ft)		Vel Total (ft/s)	5.19	4.97
Weir Sta Rgt (ft)		Flow Area (sq ft)	39.32	41.02
Weir Submerg		Froude # Chl	0.49	0.46
Weir Max Depth (ft)		Specif Force (cu ft)	97.47	101.86
Min El Weir Flow (ft)	131.95	Hydr Depth (ft)	3.28	3.42
Min El Prs (ft)	128.00	W.P. Total (ft)	18.67	18.61
Delta EG (ft)	0.29	Conv. Total (cfs)	3427.9	3688.3
Delta WS (ft)	0.30	Top Width (ft)	11.99	11.99
BR Open Area (sq ft)	112.64	Frctn Loss (ft)	0.04	0.03
BR Open Vel (ft/s)	5.19	C & E Loss (ft)	0.02	0.11
BR Sluice Coef		Shear Total (lb/sq ft)	0.47	0.42
BR Sel Method	Energy only	Power Total (lb/ft s)	2.42	2.09

Plan: Exist Pantry Brook Lower RS: 485 Profile: 25-Year

E.G. US. (ft)	122.65	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	122.30	E.G. Elev (ft)	123.11	123.03
Q Total (cfs)	305.00	W.S. Elev (ft)	122.42	122.38
Q Bridge (cfs)	305.00	Crit W.S. (ft)	121.33	121.16
Q Weir (cfs)		Max Chl Dpth (ft)	4.06	4.15
Weir Sta Lft (ft)		Vel Total (ft/s)	6.67	6.46
Weir Sta Rgt (ft)		Flow Area (sq ft)	45.71	47.25
Weir Submerg		Froude # Chl	0.58	0.56
Weir Max Depth (ft)		Specif Force (cu ft)	150.48	154.43
Min El Weir Flow (ft)	131.95	Hydr Depth (ft)	3.81	3.94
Min El Prs (ft)	128.00	W.P. Total (ft)	19.71	19.64
Delta EG (ft)	0.49	Conv. Total (cfs)	4250.2	4502.5
Delta WS (ft)	0.49	Top Width (ft)	11.99	11.99
BR Open Area (sq ft)	112.64	Frctn Loss (ft)	0.06	0.04
BR Open Vel (ft/s)	6.67	C & E Loss (ft)	0.02	0.20
BR Sluice Coef		Shear Total (lb/sq ft)	0.75	0.69
BR Sel Method	Energy only	Power Total (lb/ft s)	4.98	4.45

Plan: Exist Pantry Brook Lower RS: 485 Profile: 50-Year

E.G. US. (ft)	123.14	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	122.70	E.G. Elev (ft)	123.71	123.61
Q Total (cfs)	385.00	W.S. Elev (ft)	122.79	122.74
Q Bridge (cfs)	385.00	Crit W.S. (ft)	121.78	121.62
Q Weir (cfs)		Max Chl Dpth (ft)	4.43	4.51
Weir Sta Lft (ft)		Vel Total (ft/s)	7.67	7.47
Weir Sta Rgt (ft)		Flow Area (sq ft)	50.16	51.57
Weir Submerg		Froude # Chl	0.64	0.62
Weir Max Depth (ft)		Specif Force (cu ft)	196.87	200.37
Min El Weir Flow (ft)	131.95	Hydr Depth (ft)	4.18	4.30
Min El Prs (ft)	128.00	W.P. Total (ft)	20.47	20.40
Delta EG (ft)	0.65	Conv. Total (cfs)	4839.6	5078.3
Delta WS (ft)	0.65	Top Width (ft)	11.99	11.99
BR Open Area (sq ft)	112.64	Frctn Loss (ft)	0.07	0.04
BR Open Vel (ft/s)	7.67	C & E Loss (ft)	0.02	0.29

Plan: Exist   Pantry Brook   Lower RS: 485   Profile: 50-Year (Continued)

BR Sluice Coef		Shear Total (lb/sq ft)	0.97	0.91
BR Sel Method	Energy only	Power Total (lb/ft s)	7.43	6.77

Plan: Exist   Pantry Brook   Lower RS: 485   Profile: 100-Year

E.G. US. (ft)	123.71	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	123.18	E.G. Elev (ft)	124.35	124.23
Q Total (cfs)	476.00	W.S. Elev (ft)	123.17	123.11
Q Bridge (cfs)	476.00	Crit W.S. (ft)	122.27	122.10
Q Weir (cfs)		Max Chl Dpth (ft)	4.81	4.88
Weir Sta Lft (ft)		Vel Total (ft/s)	8.69	8.50
Weir Sta Rgt (ft)		Flow Area (sq ft)	54.75	55.98
Weir Submerg		Froude # Chl	0.70	0.68
Weir Max Depth (ft)		Specif Force (cu ft)	253.71	256.62
Min El Weir Flow (ft)	131.95	Hydr Depth (ft)	4.56	4.67
Min El Prs (ft)	128.00	W.P. Total (ft)	21.23	21.10
Delta EG (ft)	0.85	Conv. Total (cfs)	5463.7	5694.1
Delta WS (ft)	0.84	Top Width (ft)	11.99	11.99
BR Open Area (sq ft)	112.64	Frctn Loss (ft)	0.09	0.04
BR Open Vel (ft/s)	8.69	C & E Loss (ft)	0.03	0.41
BR Sluice Coef		Shear Total (lb/sq ft)	1.22	1.16
BR Sel Method	Energy only	Power Total (lb/ft s)	10.62	9.84

Plan: Exist   Pantry Brook   Lower RS: 485   Profile: 500-Year

E.G. US. (ft)	125.32	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	124.54	E.G. Elev (ft)	126.30	126.15
Q Total (cfs)	783.00	W.S. Elev (ft)	124.14	124.01
Q Bridge (cfs)	783.00	Crit W.S. (ft)	123.70	123.54
Q Weir (cfs)		Max Chl Dpth (ft)	5.78	5.78
Weir Sta Lft (ft)		Vel Total (ft/s)	11.80	11.72
Weir Sta Rgt (ft)		Flow Area (sq ft)	66.37	66.79
Weir Submerg		Froude # Chl	0.87	0.86
Weir Max Depth (ft)		Specif Force (cu ft)	470.87	471.44
Min El Weir Flow (ft)	131.95	Hydr Depth (ft)	5.53	5.57
Min El Prs (ft)	128.00	W.P. Total (ft)	23.17	22.91
Delta EG (ft)	1.64	Conv. Total (cfs)	7102.6	7233.8
Delta WS (ft)	1.63	Top Width (ft)	11.99	11.99
BR Open Area (sq ft)	112.64	Frctn Loss (ft)	0.14	0.05
BR Open Vel (ft/s)	11.80	C & E Loss (ft)	0.01	0.87
BR Sluice Coef		Shear Total (lb/sq ft)	2.17	2.13
BR Sel Method	Energy only	Power Total (lb/ft s)	25.64	25.00

Plan: Exist Pantry Brook Lower RS: 505 Profile: 25-Year

E.G. Elev (ft)	122.65	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.35	Wt. n-Val.	0.039	0.028	0.033
W.S. Elev (ft)	122.30	Reach Len. (ft)	15.00	15.00	15.00
Crit W.S. (ft)	120.83	Flow Area (sq ft)	1.93	61.97	3.04
E.G. Slope (ft/ft)	0.001679	Area (sq ft)	1.93	61.97	3.04
Q Total (cfs)	305.00	Flow (cfs)	2.65	297.93	4.41
Top Width (ft)	21.09	Top Width (ft)	1.47	17.04	2.57
Vel Total (ft/s)	4.56	Avg. Vel. (ft/s)	1.37	4.81	1.45
Max Chl Dpth (ft)	3.94	Hydr. Depth (ft)	1.31	3.64	1.18
Conv. Total (cfs)	7444.4	Conv. (cfs)	64.7	7271.9	107.7
Length Wtd. (ft)	15.00	Wetted Per. (ft)	2.98	18.85	3.46
Min Ch El (ft)	118.36	Shear (lb/sq ft)	0.07	0.34	0.09
Alpha	1.09	Stream Power (lb/ft s)	0.09	1.66	0.13
Frctn Loss (ft)	0.03	Cum Volume (acre-ft)	1.94	0.72	1.67
C & E Loss (ft)	0.14	Cum SA (acres)	1.36	0.21	0.86

Plan: Exist Pantry Brook Lower RS: 505 Profile: 50-Year

E.G. Elev (ft)	123.14	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.45	Wt. n-Val.	0.039	0.028	0.034
W.S. Elev (ft)	122.70	Reach Len. (ft)	15.00	15.00	15.00
Crit W.S. (ft)	121.19	Flow Area (sq ft)	2.52	68.73	4.14
E.G. Slope (ft/ft)	0.001867	Area (sq ft)	2.52	68.73	4.14
Q Total (cfs)	385.00	Flow (cfs)	4.25	373.40	7.35
Top Width (ft)	21.53	Top Width (ft)	1.49	17.04	3.00
Vel Total (ft/s)	5.11	Avg. Vel. (ft/s)	1.68	5.43	1.78
Max Chl Dpth (ft)	4.34	Hydr. Depth (ft)	1.69	4.03	1.38
Conv. Total (cfs)	8909.5	Conv. (cfs)	98.3	8641.1	170.2
Length Wtd. (ft)	15.00	Wetted Per. (ft)	3.38	18.85	4.04
Min Ch El (ft)	118.36	Shear (lb/sq ft)	0.09	0.43	0.12
Alpha	1.10	Stream Power (lb/ft s)	0.15	2.31	0.21
Frctn Loss (ft)	0.03	Cum Volume (acre-ft)	2.62	0.82	2.10
C & E Loss (ft)	0.19	Cum SA (acres)	1.45	0.21	0.91

APPENDIX 6.6:

PROPOSED HEC-RAS MODEL AND RESULTS

Geometry Plan

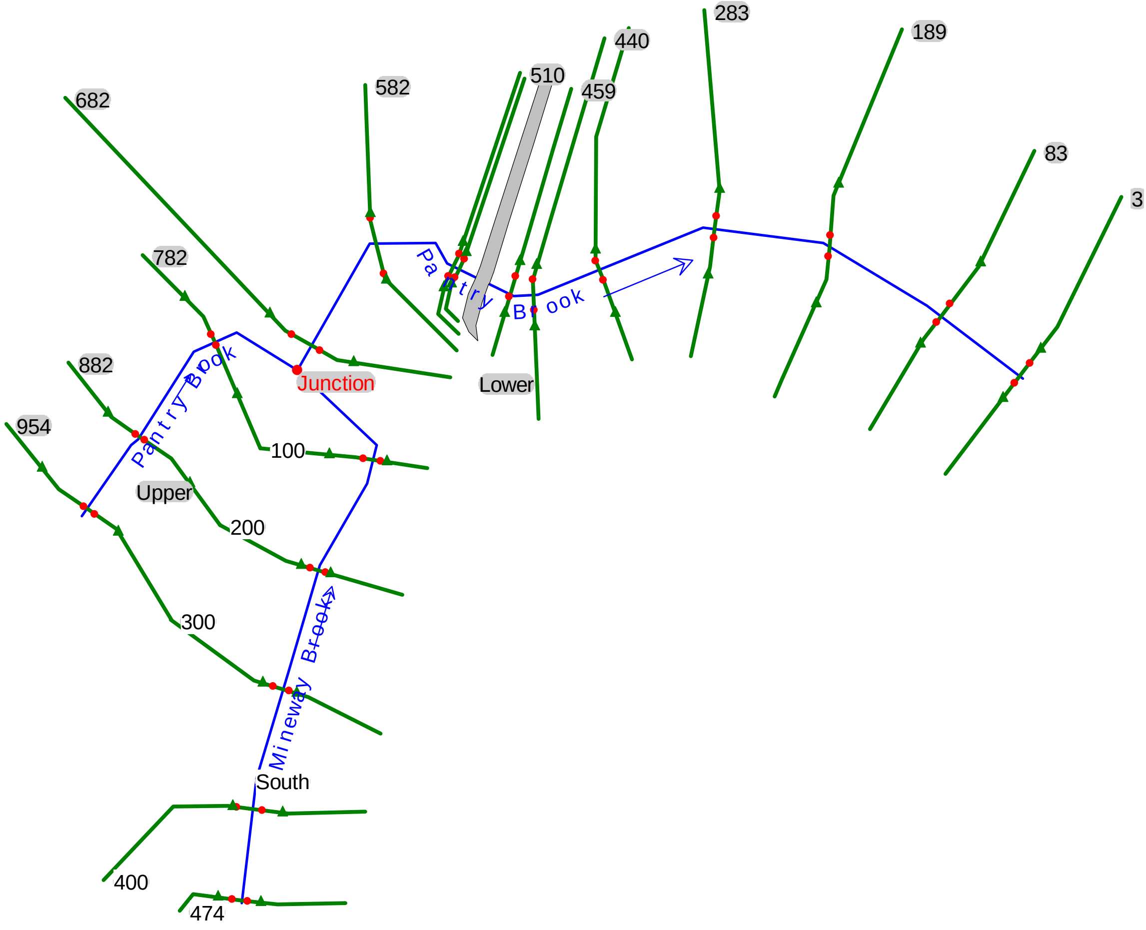
Stream Profile

Stream Cross Sections

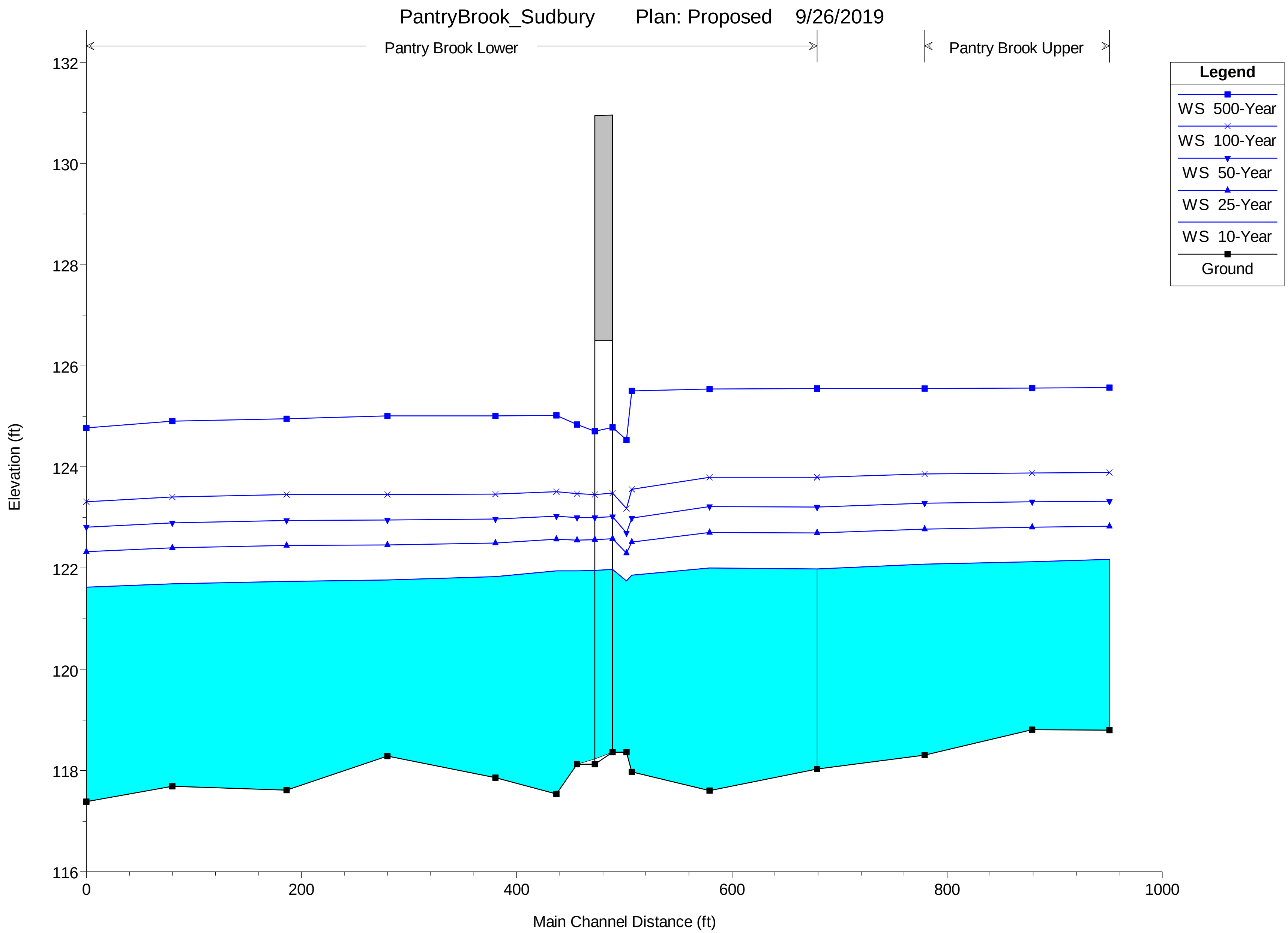
Cross Section Output Table

Detailed Bridge Output

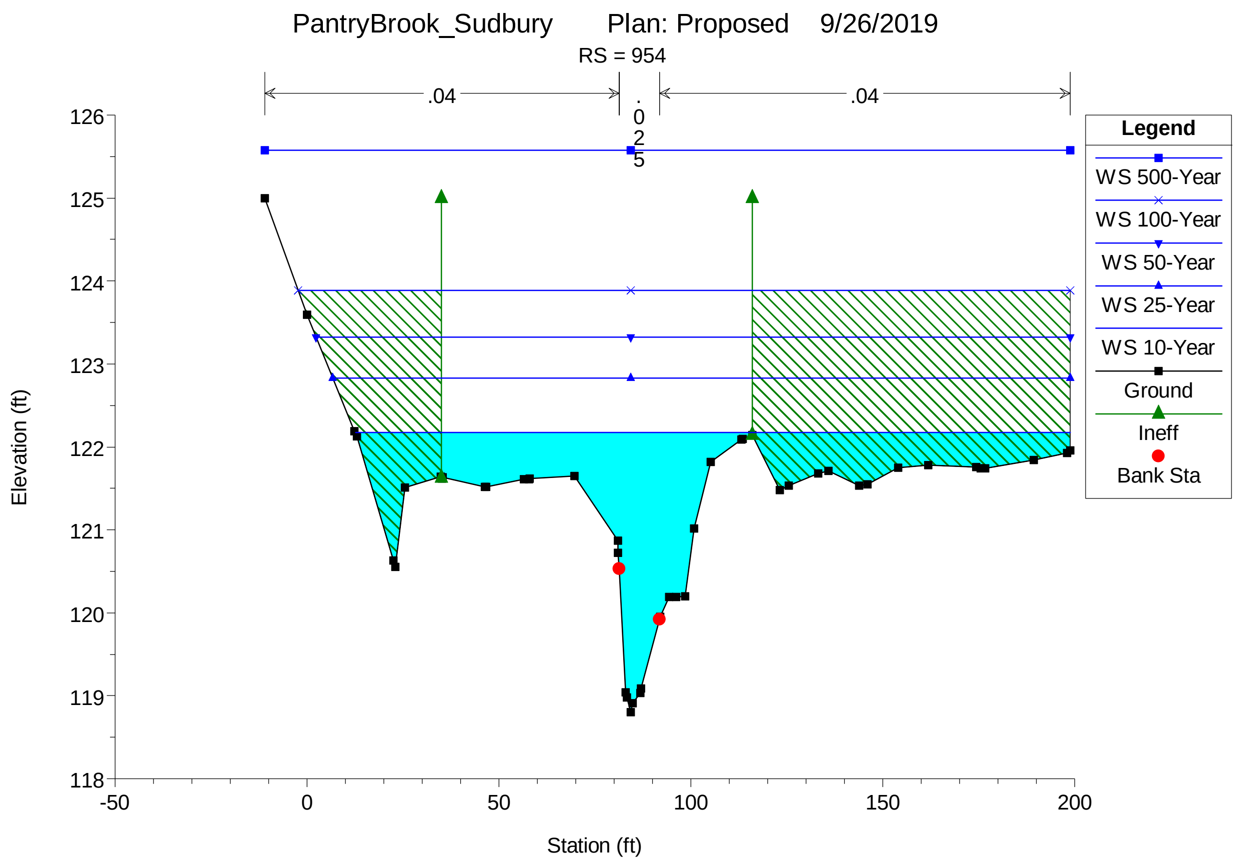
Detailed Output for Cross Section 505
(25-Year and 50-Year Storm Events)

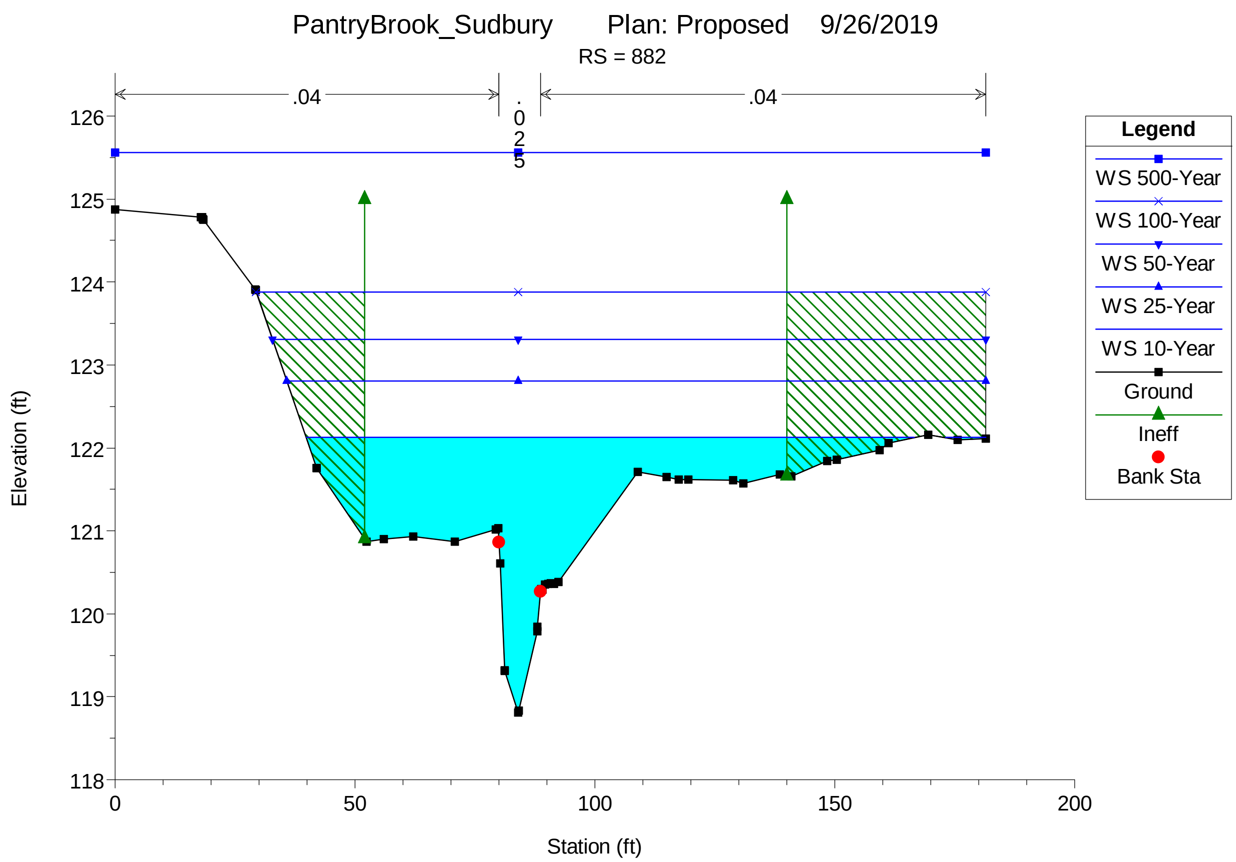


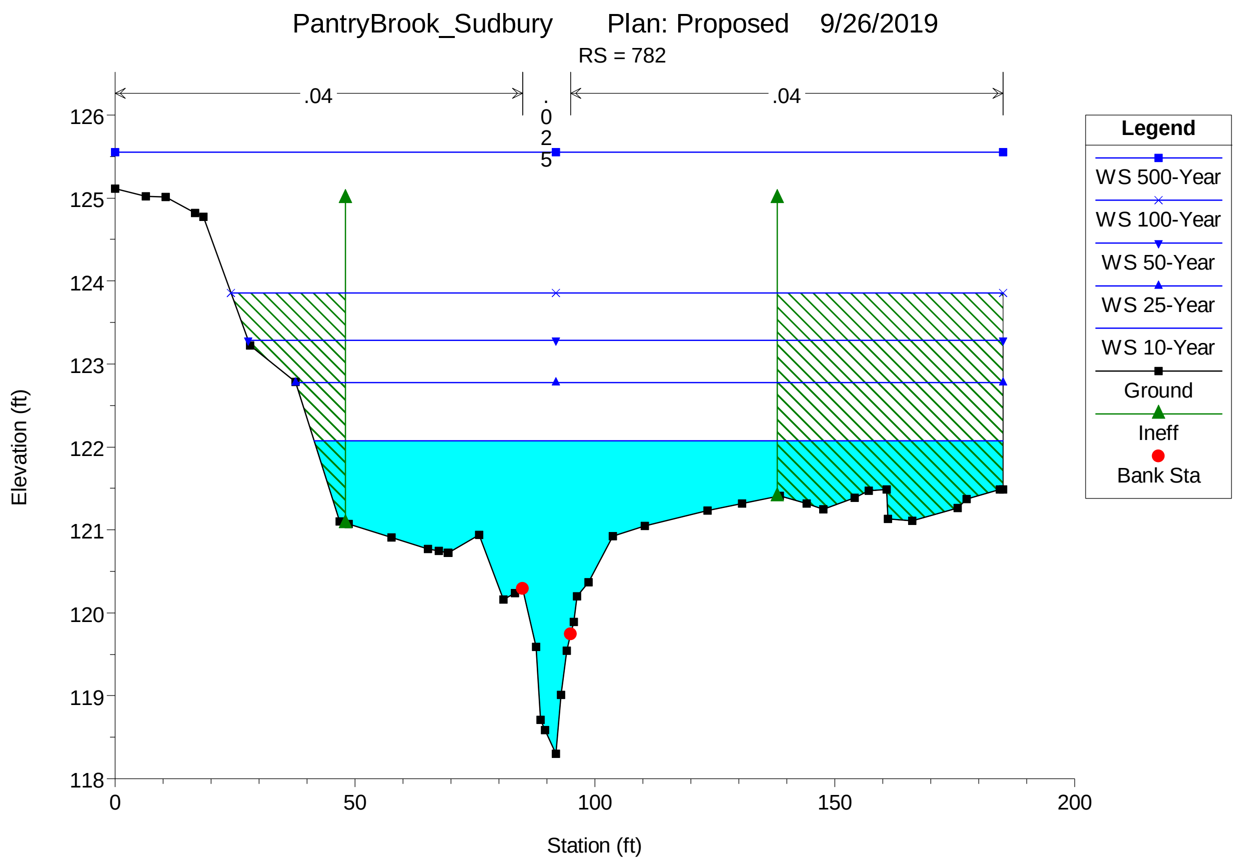
HEC-RAS Geometry Data
E. Princeton Rd over E. Wachusett Brk



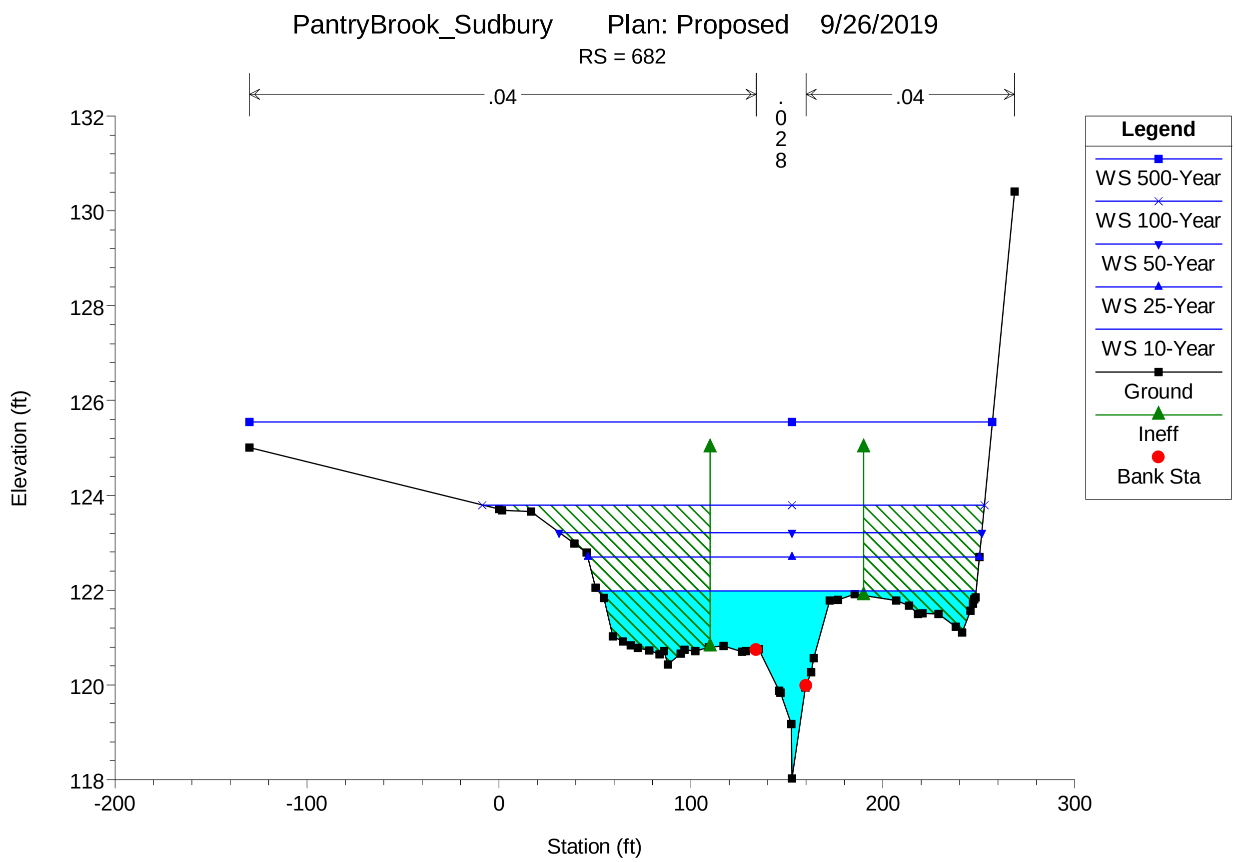
PantryBrook_Sudbury Plan: Proposed 9/26/2019
Pantry Brook Lower
Pantry Brook Upper
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Elevation (ft)
Main Channel Distance (ft)
132
130
128
126
124
122
120
118
116
0
200
400
600
800
1000


PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 954
.04
.025
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
126
125
124
123
122
121
120
119
118
-50
0
50
100
150
200

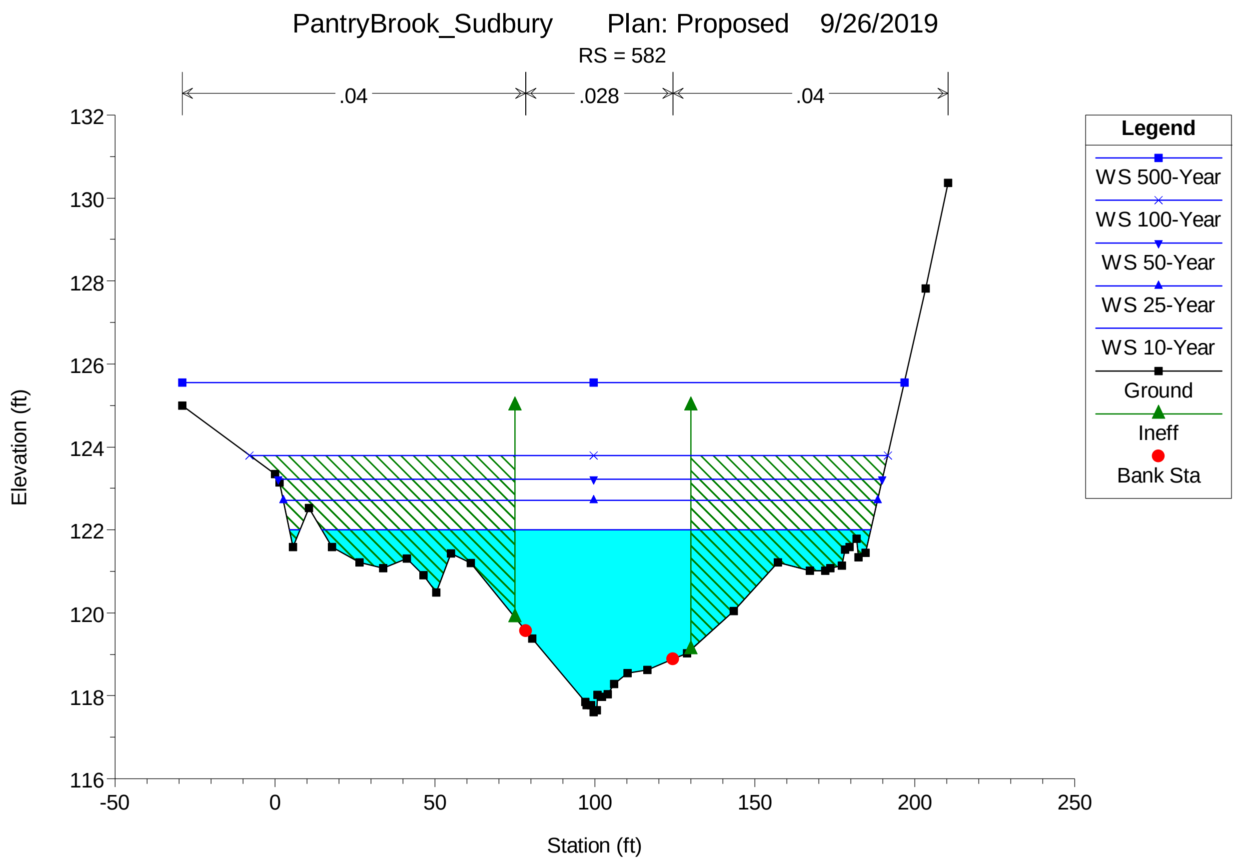

PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 882
.04
.025
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
126
125
124
123
122
121
120
119
118
0
50
100
150
200



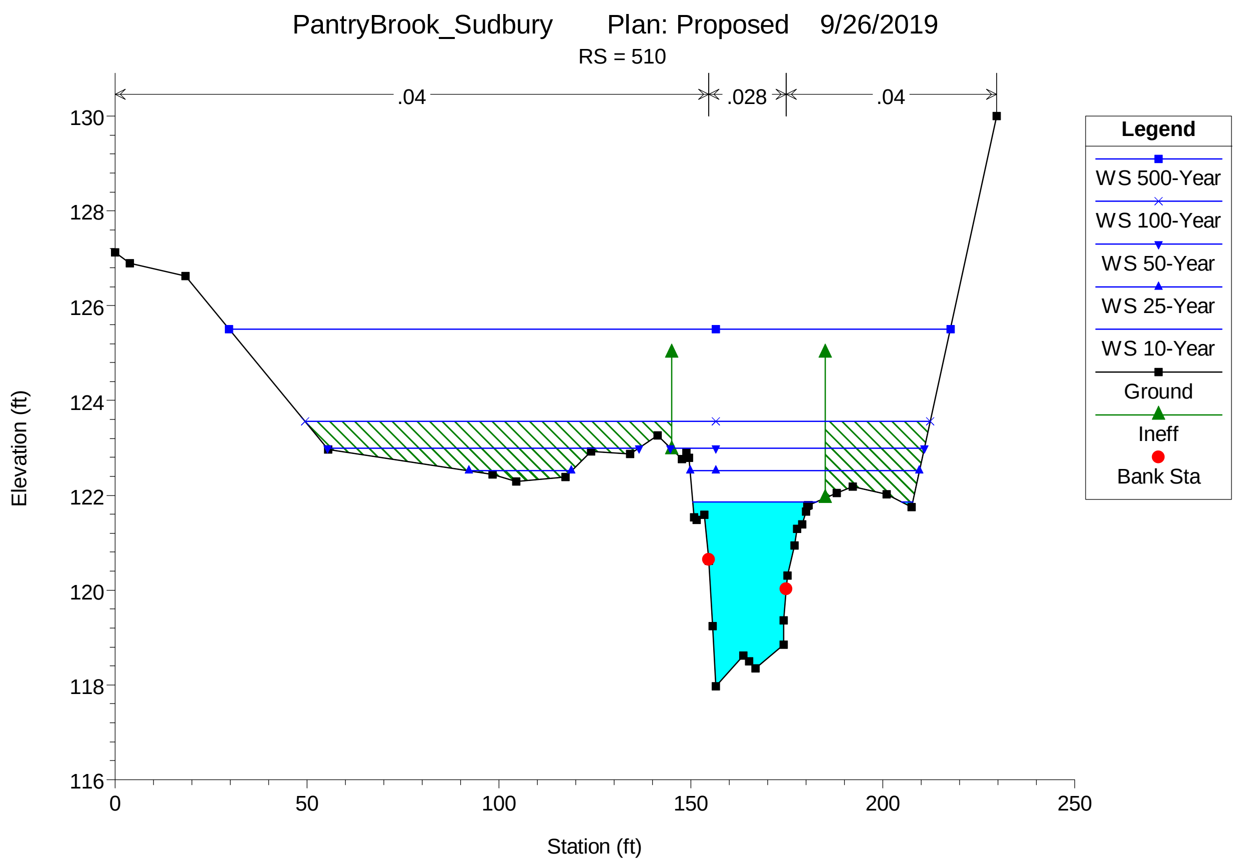
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 782
.04
.025
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
118
119
120
121
122
123
124
125
126
0
50
100
150
200
Station (ft)



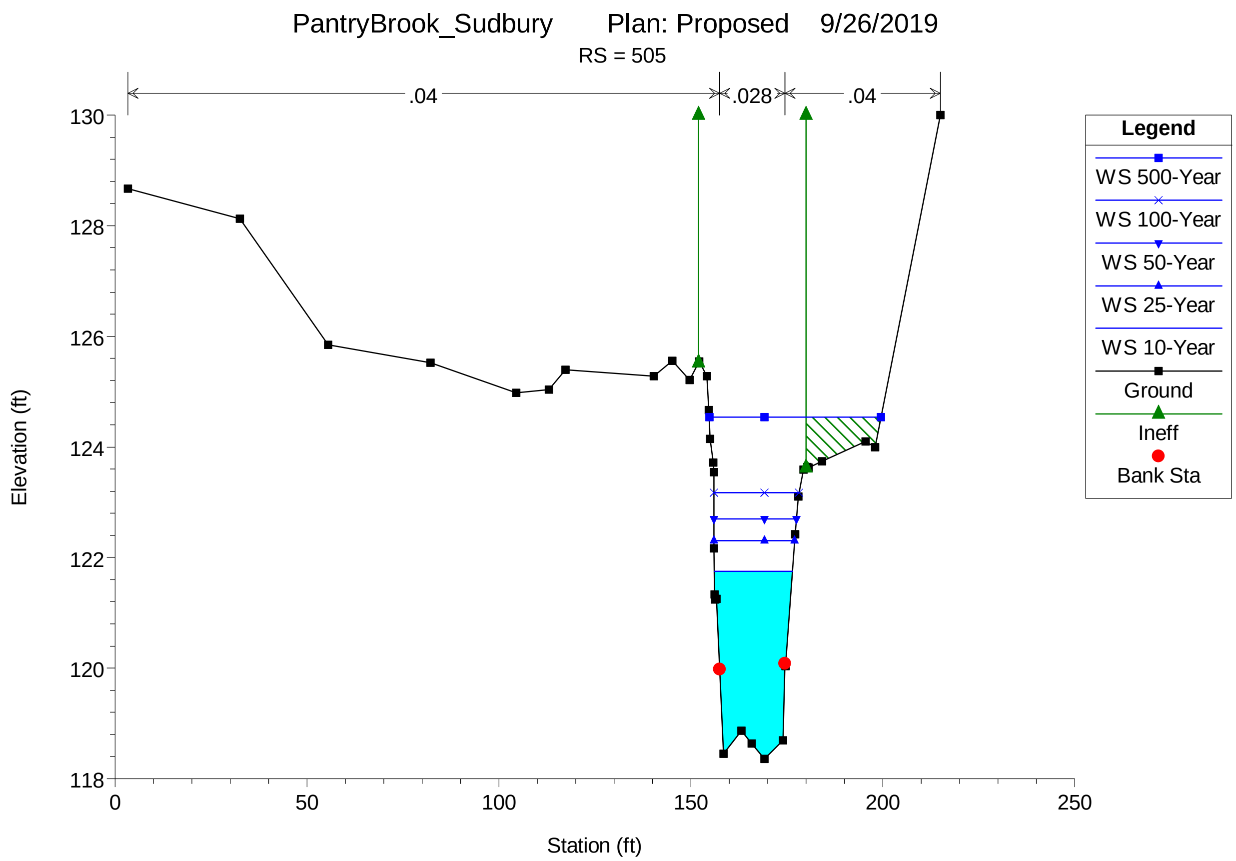
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 682
.04
.028
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
118
120
122
124
126
128
130
132
-200
-100
0
100
200
300
Station (ft)



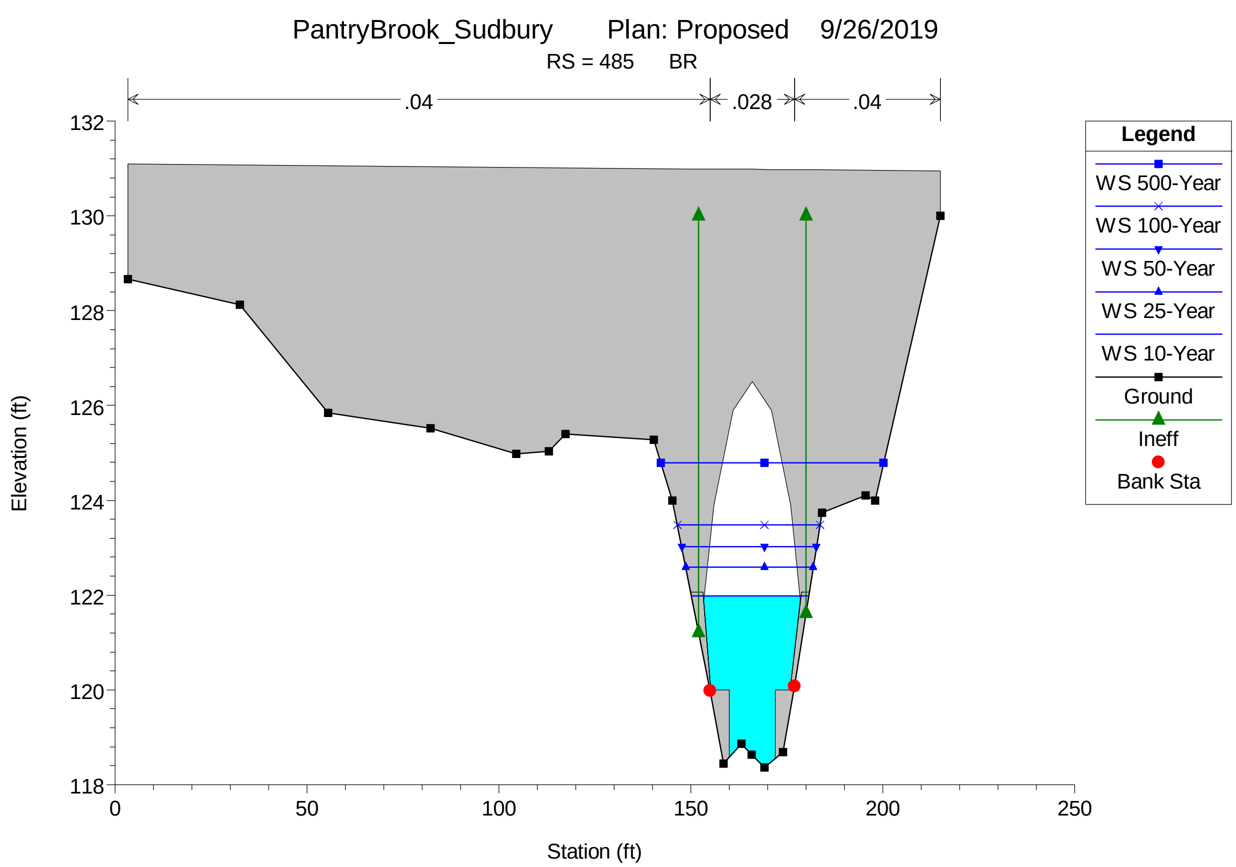
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 582
.04
.028
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
132
130
128
126
124
122
120
118
116
-50
0
50
100
150
200
250



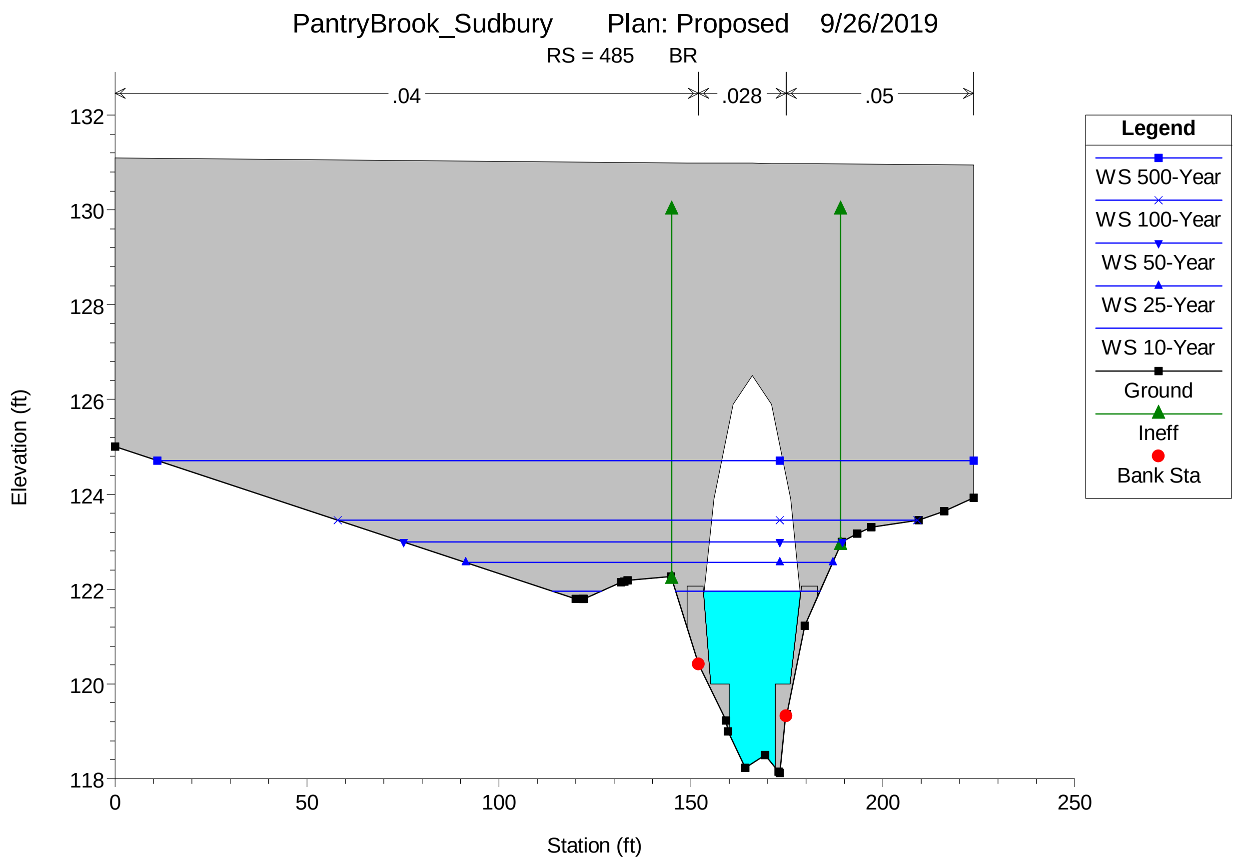
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 510
.04
.028
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
130
128
126
124
122
120
118
116
0
50
100
150
200
250

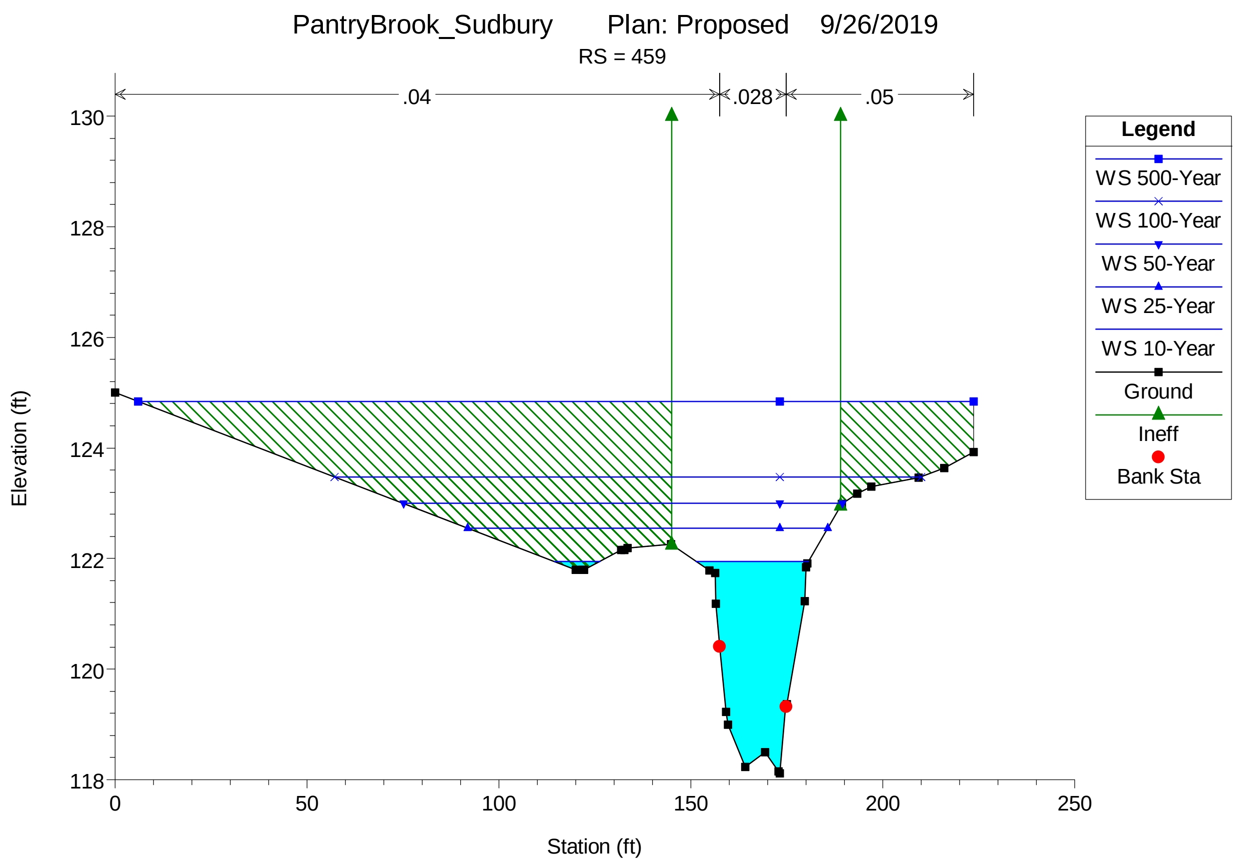


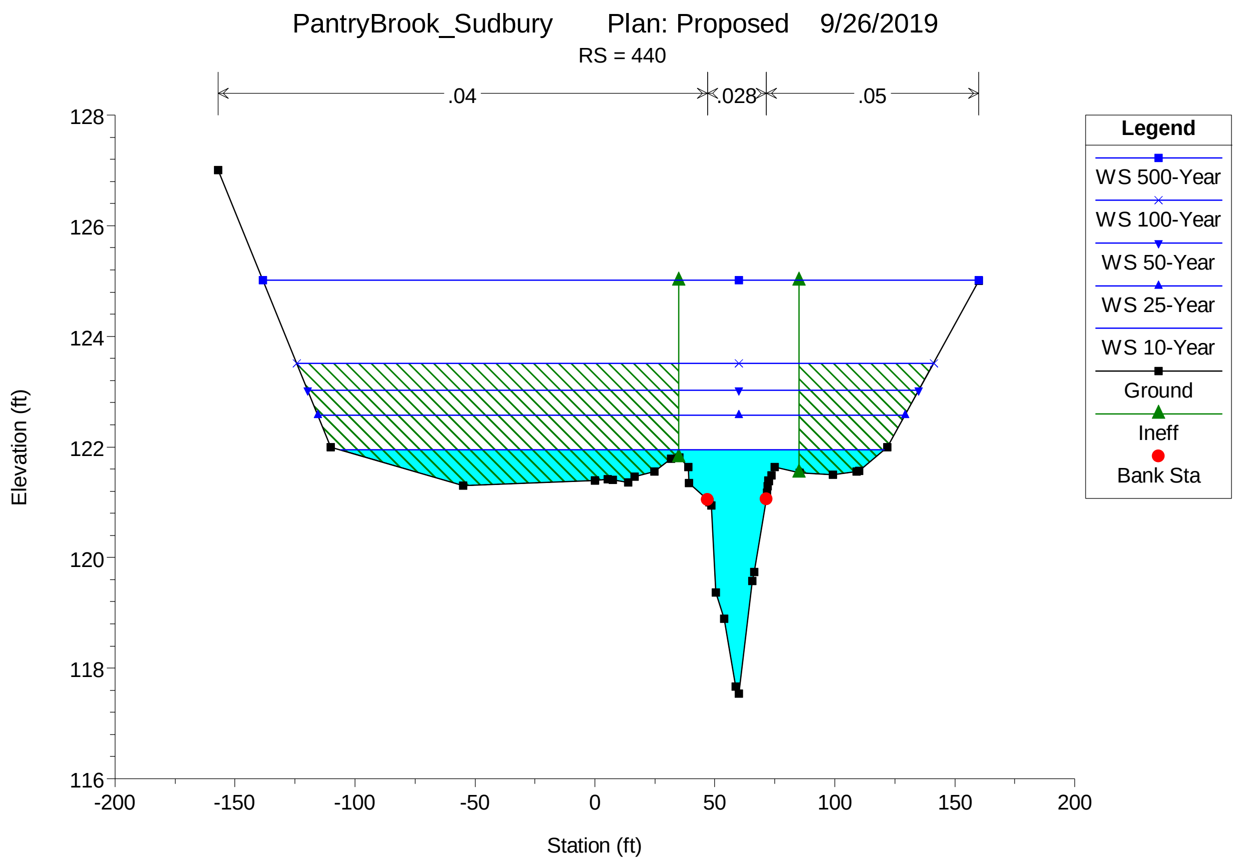
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 505
.04
.028
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

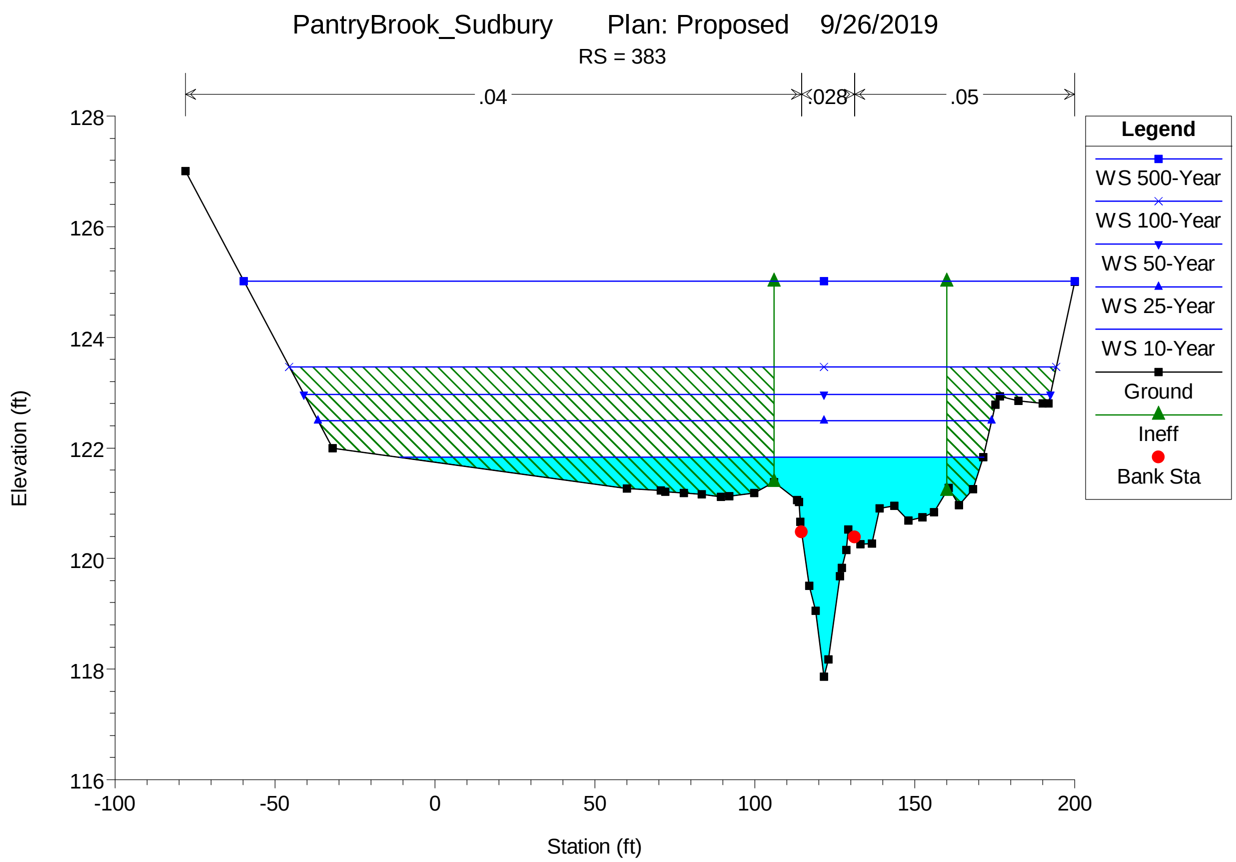


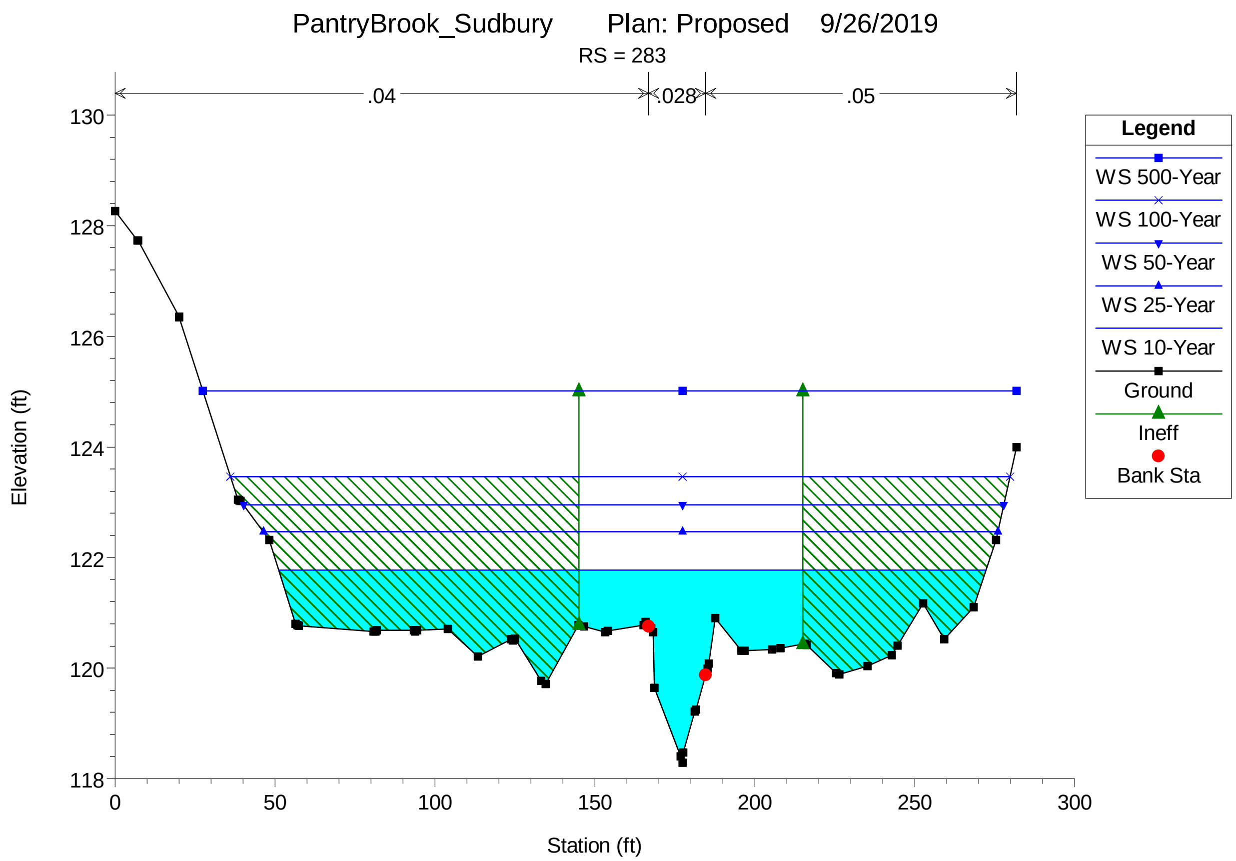
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 485 BR
.04
.028
.04
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 485 BR
.04
.028
.05
Elevation (ft)
Station (ft)
132
130
128
126
124
122
120
118
0
50
100
150
200
250
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta

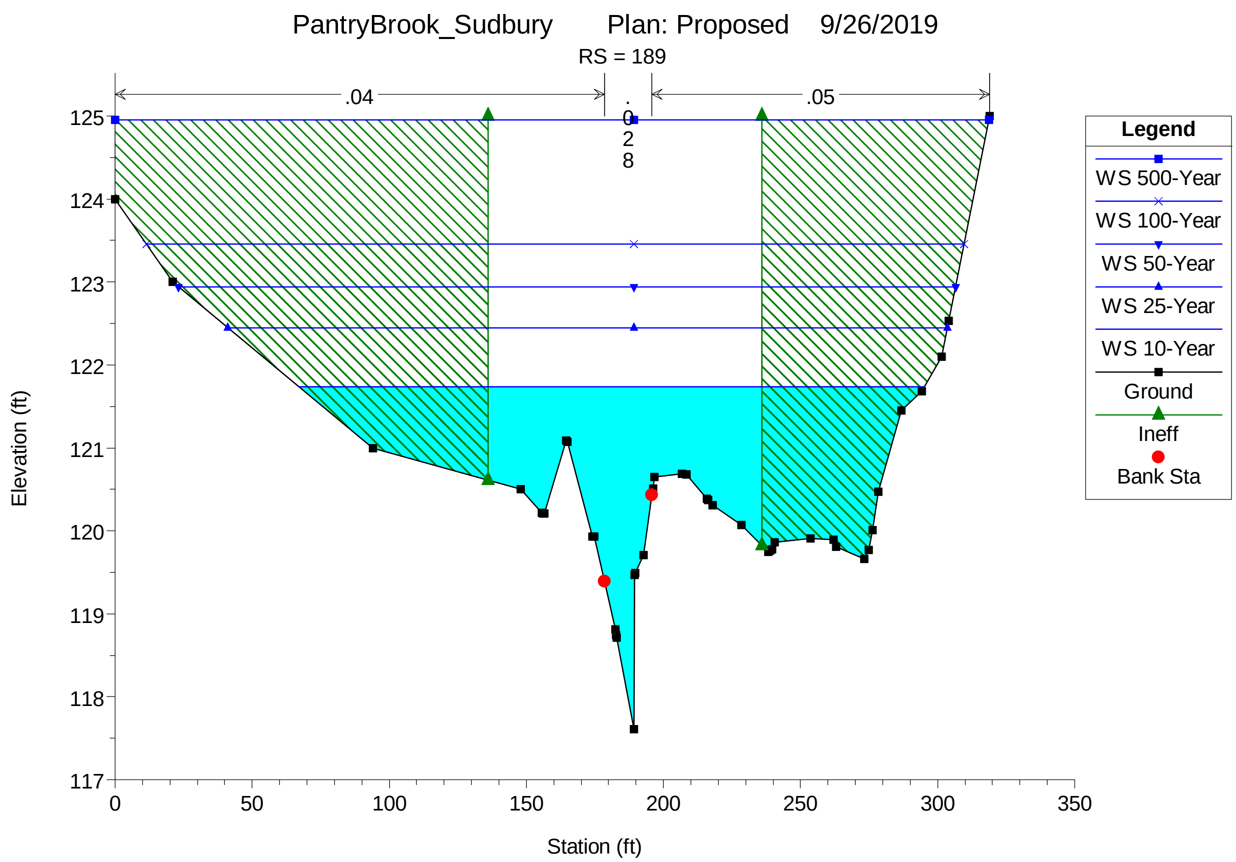

PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 459
.04
.028
.05
Elevation (ft)
Station (ft)
130
128
126
124
122
120
118
0
50
100
150
200
250
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta


PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 440
.04
.028
.05
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
128
126
124
122
120
118
116
-200
-150
-100
-50
0
50
100
150
200
Station (ft)

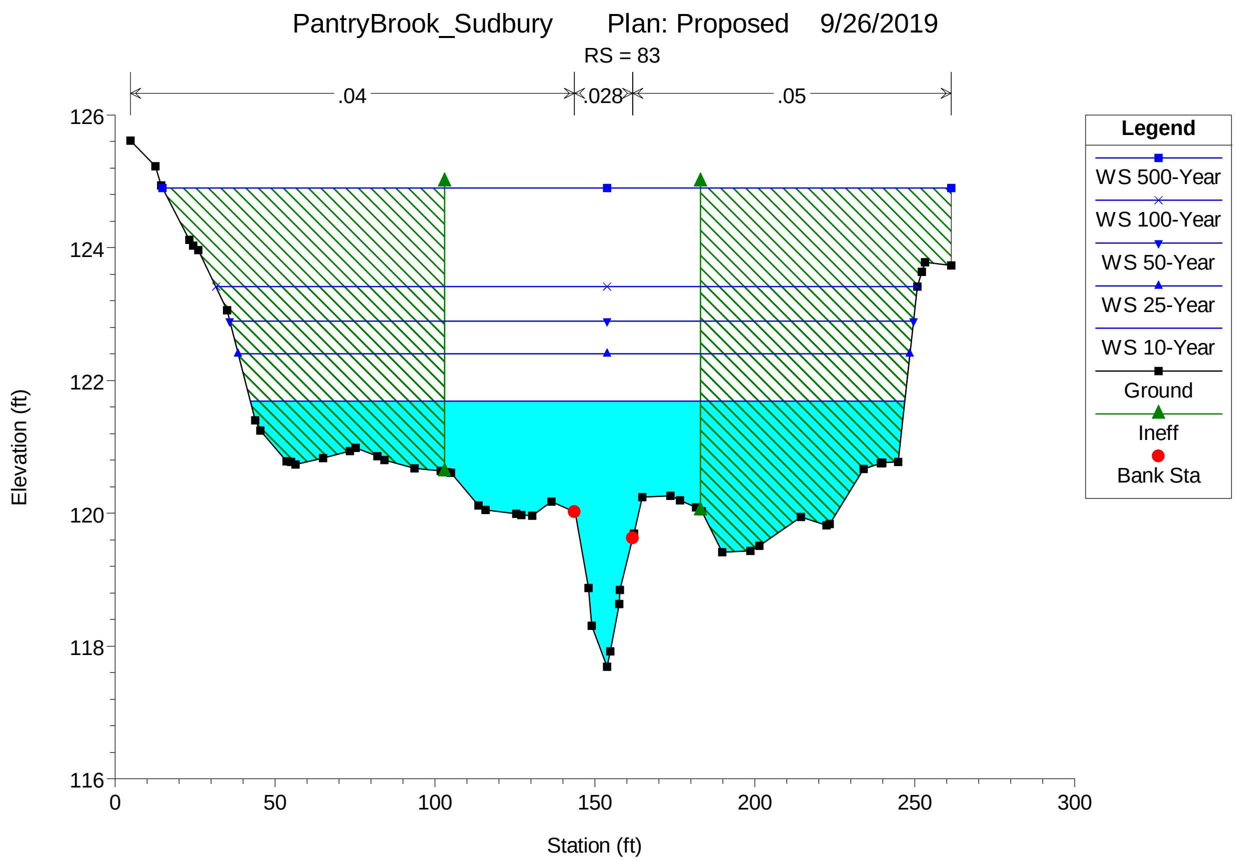

PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 383
.04
.028
.05
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
128
126
124
122
120
118
116
-100
-50
0
50
100
150
200
Station (ft)



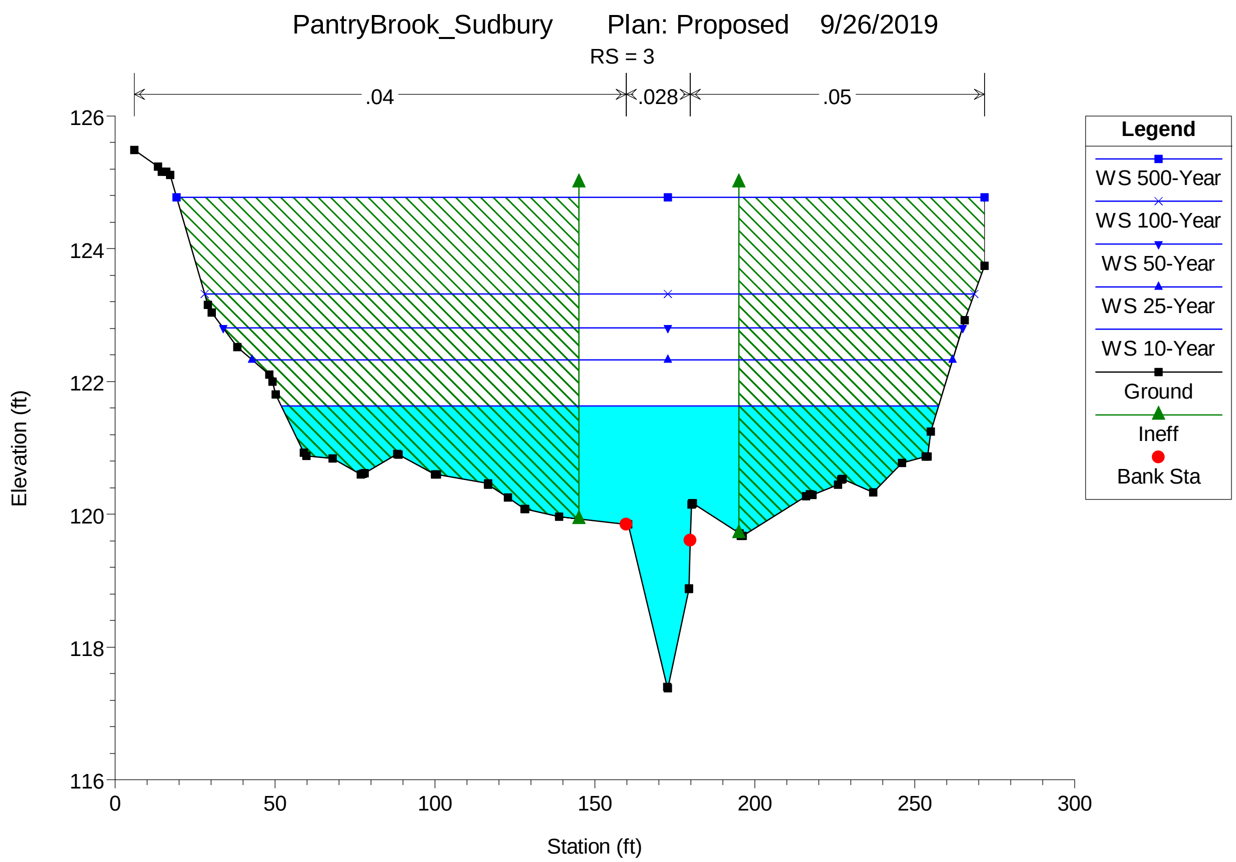
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 283
.04
.028
.05
Elevation (ft)
Station (ft)
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta



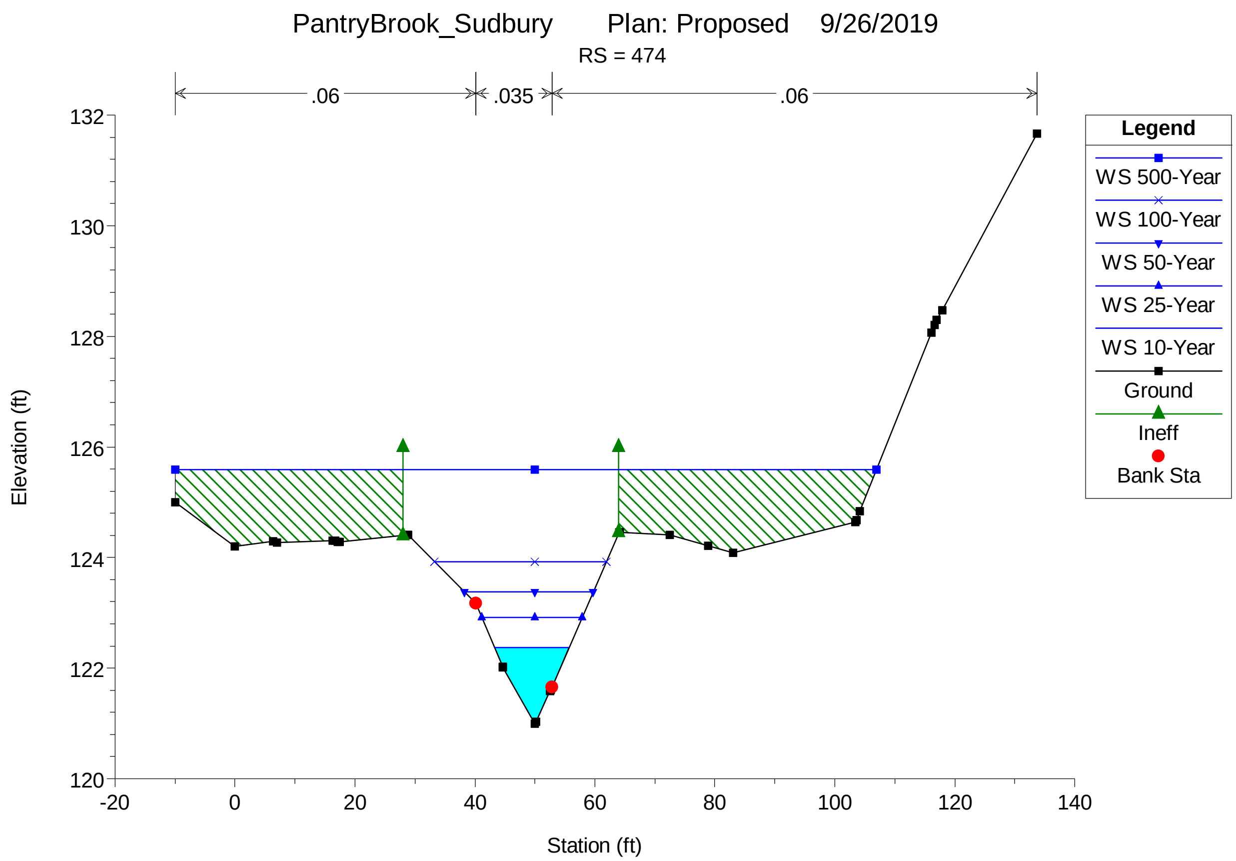
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 189
.04
.028
.05
Elevation (ft)
Station (ft)
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta



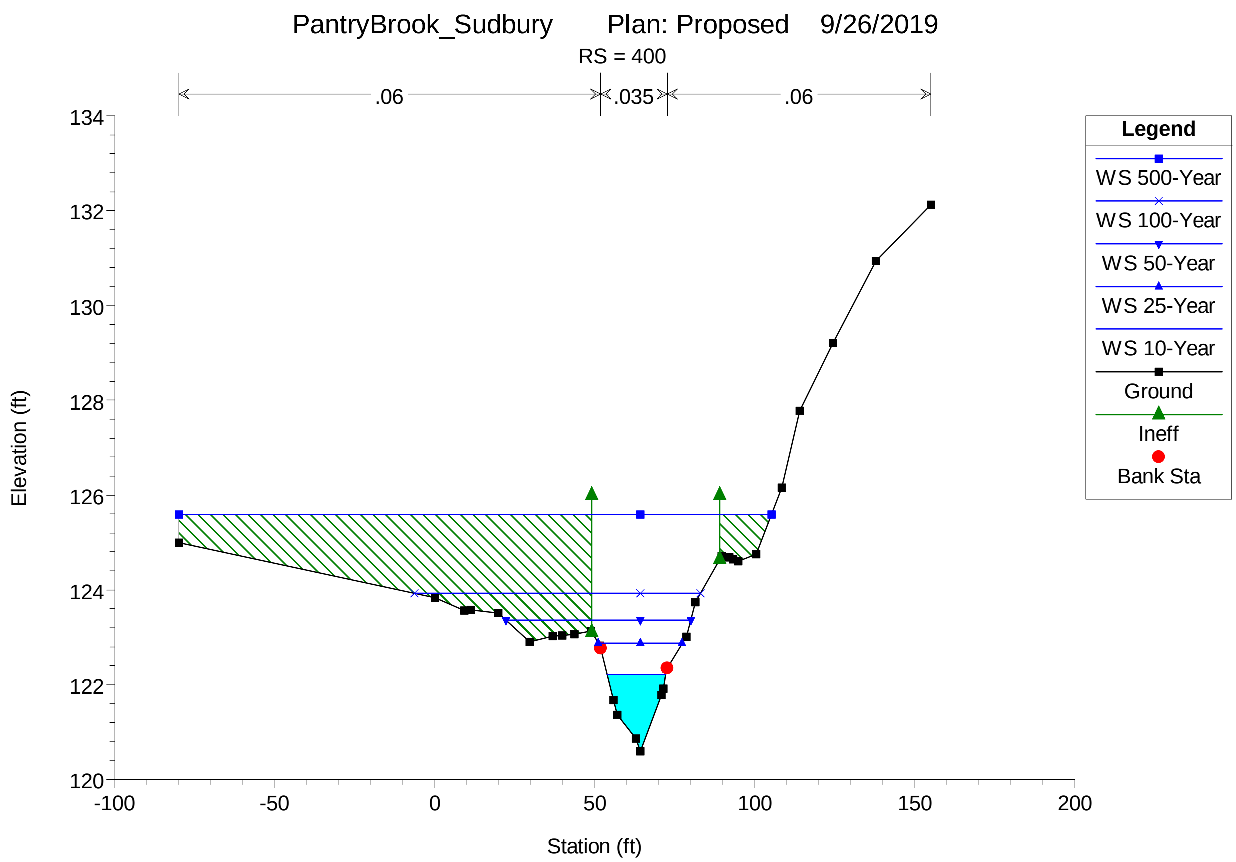
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 83
.04
.028
.05
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
126
124
122
120
118
116
0
50
100
150
200
250
300



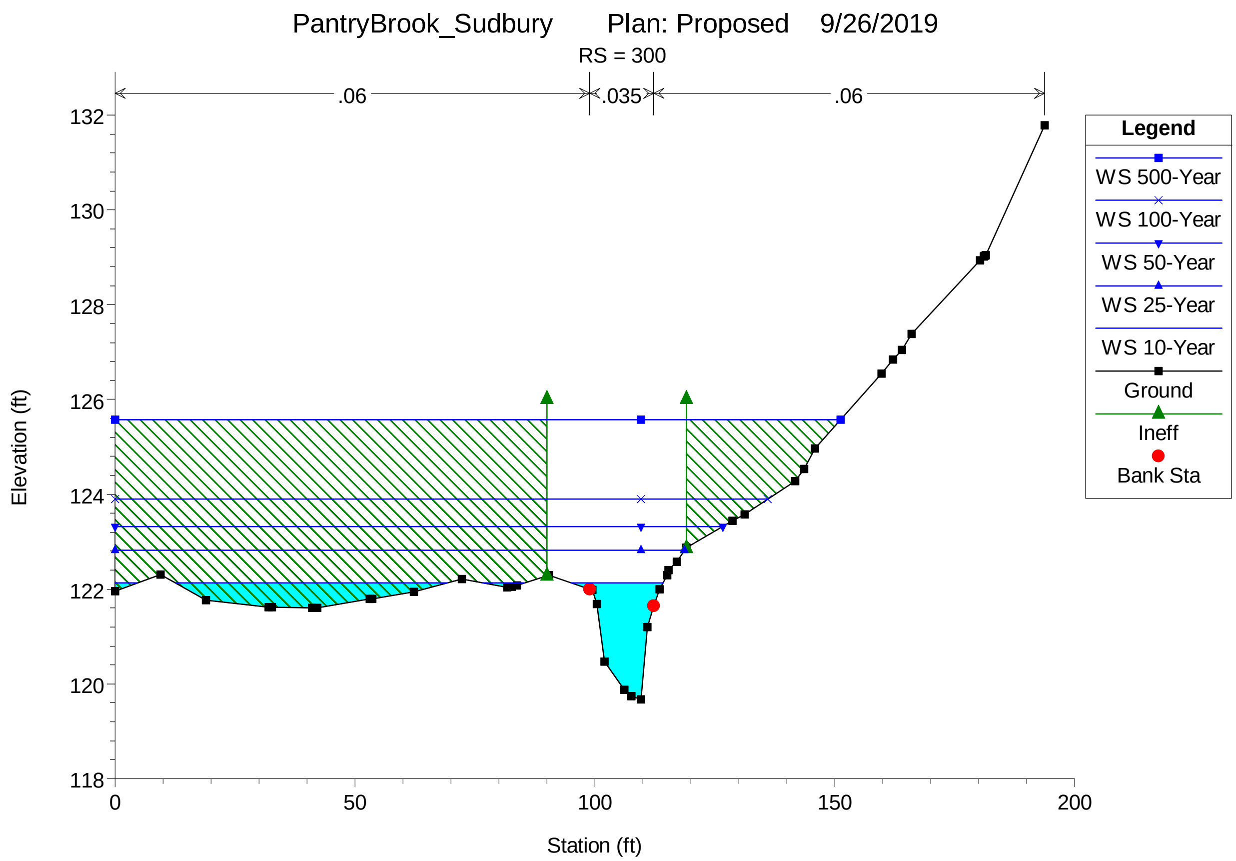
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 3
.04
.028
.05
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
126
124
122
120
118
116
0
50
100
150
200
250
300



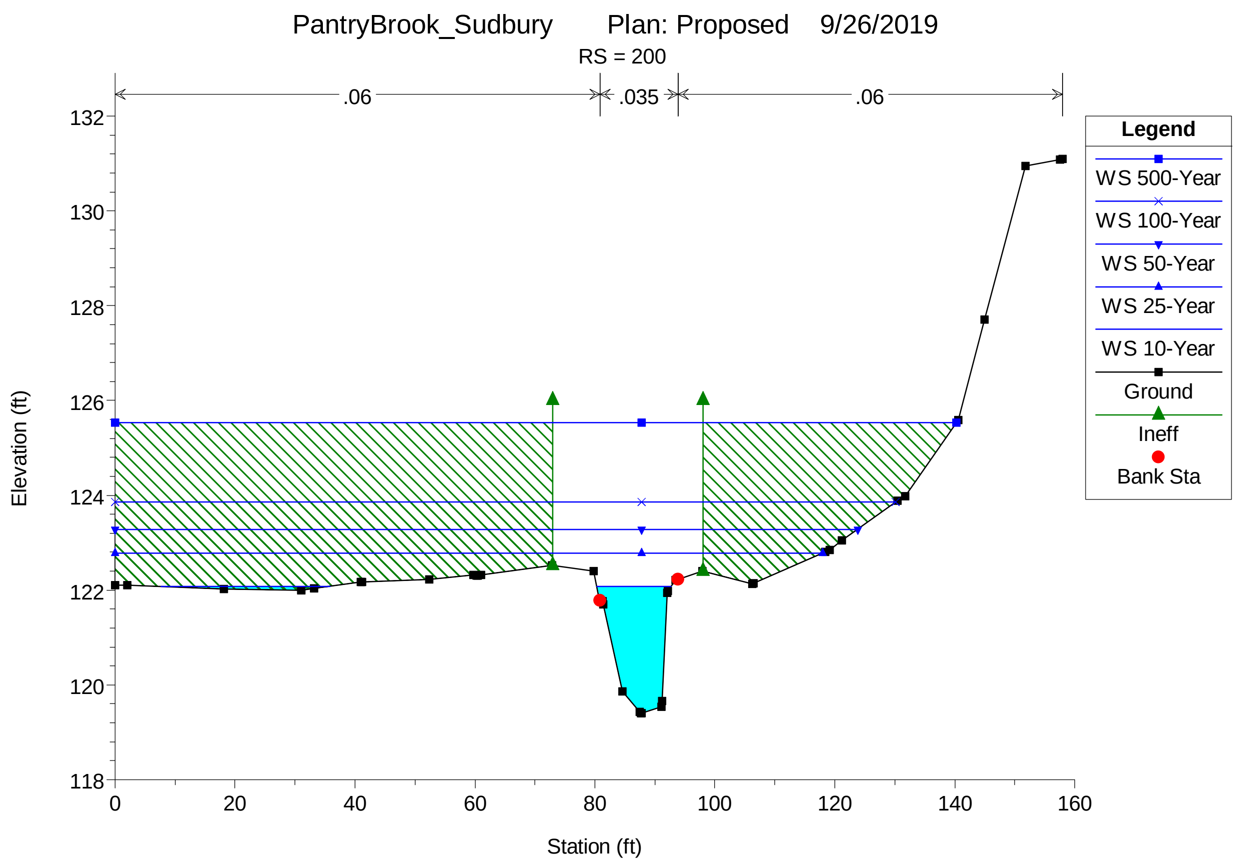
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 474
.06
.035
.06
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
120
122
124
126
128
130
132
-20
0
20
40
60
80
100
120
140



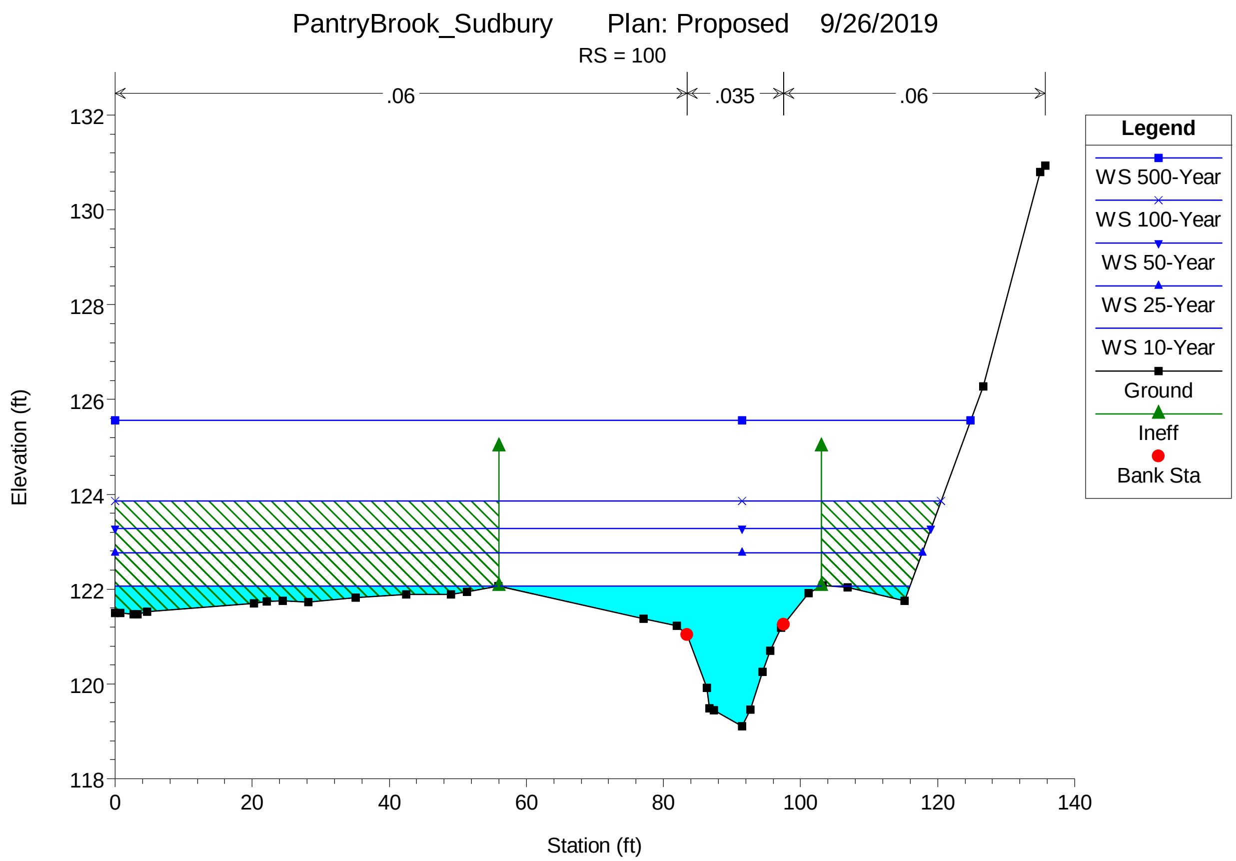
PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 400
.06
.035
.06
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
120
122
124
126
128
130
132
134
-100
-50
0
50
100
150
200



PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 300
.06
.035
.06
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)



PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 200
.06
.035
.06
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)



PantryBrook_Sudbury Plan: Proposed 9/26/2019
RS = 100
.06
.035
.06
Legend
WS 500-Year
WS 100-Year
WS 50-Year
WS 25-Year
WS 10-Year
Ground
Ineff
Bank Sta
Elevation (ft)
132
130
128
126
124
122
120
118
0
20
40
60
80
100
120
140
Station (ft)

HEC-RAS Plan: Proposed

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Upper	954	10-Year	176.00	118.80	122.17	121.29	122.32	0.001056	3.71	83.14	186.20	0.39
Upper	954	25-Year	259.00	118.80	122.83	121.92	122.94	0.000702	3.48	136.39	192.06	0.33
Upper	954	50-Year	324.00	118.80	123.32	122.14	123.41	0.000541	3.33	176.26	196.42	0.29
Upper	954	100-Year	398.00	118.80	123.89	122.33	123.97	0.000414	3.19	222.20	201.13	0.26
Upper	954	500-Year	640.00	118.80	125.57	122.78	125.58	0.000062	1.52	817.23	209.79	0.11
Upper	882	10-Year	176.00	118.81	122.12	121.54	122.23	0.001075	3.52	97.10	135.00	0.38
Upper	882	25-Year	259.00	118.81	122.81	121.87	122.88	0.000621	3.10	157.30	145.71	0.30
Upper	882	50-Year	324.00	118.81	123.31	122.02	123.37	0.000465	2.94	201.27	148.67	0.26
Upper	882	100-Year	398.00	118.81	123.88	122.17	123.93	0.000352	2.80	251.62	152.06	0.23
Upper	882	500-Year	640.00	118.81	125.56	122.55	125.58	0.000099	1.84	651.82	181.46	0.13
Upper	782	10-Year	176.00	118.30	122.08	121.30	122.14	0.000576	2.75	122.51	143.62	0.28
Upper	782	25-Year	259.00	118.30	122.78	121.57	122.82	0.000379	2.58	185.40	147.44	0.24
Upper	782	50-Year	324.00	118.30	123.28	121.71	123.33	0.000304	2.52	230.94	157.33	0.22
Upper	782	100-Year	398.00	118.30	123.86	121.86	123.90	0.000243	2.46	282.93	160.94	0.20
Upper	782	500-Year	640.00	118.30	125.55	122.24	125.57	0.000071	1.63	723.53	185.05	0.11
Lower	682	10-Year	204.00	118.03	121.98	121.04	122.07	0.000857	2.57	103.59	197.02	0.30
Lower	682	25-Year	305.00	118.03	122.70	121.33	122.77	0.000587	2.56	160.73	204.26	0.26
Lower	682	50-Year	385.00	118.03	123.21	121.52	123.29	0.000479	2.58	201.73	220.20	0.24
Lower	682	100-Year	476.00	118.03	123.80	121.71	123.87	0.000388	2.57	248.44	261.62	0.23
Lower	682	500-Year	783.00	118.03	125.55	122.29	125.56	0.000047	1.14	1184.85	387.15	0.08
Lower	582	10-Year	204.00	117.60	122.01	119.35	122.03	0.000092	1.16	185.22	175.13	0.11
Lower	582	25-Year	305.00	117.60	122.71	119.61	122.74	0.000110	1.44	223.84	185.71	0.12
Lower	582	50-Year	385.00	117.60	123.22	119.79	123.25	0.000119	1.62	251.69	188.93	0.13
Lower	582	100-Year	476.00	117.60	123.79	119.99	123.84	0.000122	1.77	283.51	199.50	0.14
Lower	582	500-Year	783.00	117.60	125.54	120.52	125.56	0.000035	1.14	1029.63	225.73	0.08
Lower	510	10-Year	204.00	117.97	121.87	120.03	122.00	0.000743	2.99	72.73	35.36	0.29
Lower	510	25-Year	305.00	117.97	122.52	120.50	122.71	0.000847	3.60	95.32	86.45	0.32
Lower	510	50-Year	385.00	117.97	122.99	120.83	123.22	0.000869	3.94	112.87	147.38	0.33
Lower	510	100-Year	476.00	117.97	123.56	121.19	123.80	0.000828	4.16	135.47	162.86	0.33
Lower	510	500-Year	783.00	117.97	125.50	122.33	125.55	0.000174	2.38	594.44	187.88	0.16
Lower	505	10-Year	204.00	118.36	121.74	120.31	121.97	0.001328	3.83	55.42	20.35	0.38
Lower	505	25-Year	305.00	118.36	122.30	120.83	122.65	0.001679	4.81	66.94	21.09	0.44
Lower	505	50-Year	385.00	118.36	122.70	121.19	123.14	0.001867	5.43	75.39	21.53	0.48
Lower	505	100-Year	476.00	118.36	123.18	121.59	123.71	0.001929	5.95	85.85	22.21	0.49
Lower	505	500-Year	783.00	118.36	124.54	122.71	125.32	0.002052	7.32	118.76	44.75	0.53
Lower	485		Bridge									
Lower	459	10-Year	204.00	118.12	121.94	120.25	122.11	0.000860	3.35	67.75	40.99	0.32
Lower	459	25-Year	305.00	118.12	122.55	120.75	122.79	0.001024	4.09	89.91	93.83	0.36
Lower	459	50-Year	385.00	118.12	123.00	121.11	123.27	0.001061	4.47	108.89	114.36	0.38
Lower	459	100-Year	476.00	118.12	123.48	121.49	123.78	0.001056	4.78	129.98	152.81	0.38
Lower	459	500-Year	783.00	118.12	124.84	122.72	125.23	0.001030	5.56	189.92	217.55	0.39
Lower	440	10-Year	204.00	117.54	121.95	120.33	122.08	0.000868	2.94	78.80	226.35	0.31
Lower	440	25-Year	305.00	117.54	122.57	120.85	122.73	0.000857	3.36	110.07	244.63	0.32
Lower	440	50-Year	385.00	117.54	123.03	121.22	123.21	0.000822	3.58	132.93	254.71	0.32
Lower	440	100-Year	476.00	117.54	123.52	121.61	123.71	0.000781	3.78	157.26	265.45	0.32
Lower	440	500-Year	783.00	117.54	125.02	122.49	125.04	0.000081	1.48	969.67	298.39	0.11
Lower	383	10-Year	204.00	117.86	121.83	121.11	122.01	0.001612	3.78	78.88	182.41	0.42
Lower	383	25-Year	305.00	117.86	122.50	121.53	122.67	0.001288	3.95	114.79	210.64	0.39
Lower	383	50-Year	385.00	117.86	122.97	121.76	123.15	0.001138	4.08	140.39	233.27	0.38
Lower	383	100-Year	476.00	117.86	123.47	121.99	123.66	0.001024	4.21	167.29	239.73	0.37
Lower	383	500-Year	783.00	117.86	125.01	122.62	125.03	0.000102	1.64	877.57	259.72	0.12
Lower	283	10-Year	204.00	118.29	121.77	120.95	121.86	0.000925	2.92	109.11	221.09	0.32
Lower	283	25-Year	305.00	118.29	122.46	121.25	122.55	0.000704	2.99	157.70	229.61	0.29
Lower	283	50-Year	385.00	118.29	122.95	121.43	123.04	0.000617	3.07	191.77	237.69	0.28
Lower	283	100-Year	476.00	118.29	123.46	121.62	123.55	0.000555	3.17	227.36	243.73	0.27
Lower	283	500-Year	783.00	118.29	125.01	122.13	125.02	0.000056	1.24	1076.02	254.38	0.09
Lower	189	10-Year	204.00	117.61	121.74	120.69	121.78	0.000495	2.15	158.06	228.27	0.23
Lower	189	25-Year	305.00	117.61	122.45	120.97	122.49	0.000366	2.16	229.04	262.55	0.21
Lower	189	50-Year	385.00	117.61	122.94	121.15	122.99	0.000318	2.20	278.41	283.54	0.20
Lower	189	100-Year	476.00	117.61	123.46	121.29	123.50	0.000285	2.26	329.85	298.32	0.19
Lower	189	500-Year	783.00	117.61	124.95	121.71	125.01	0.000232	2.48	479.49	318.72	0.18
Lower	83	10-Year	204.00	117.69	121.69	120.46	121.74	0.000392	2.13	149.77	204.48	0.22
Lower	83	25-Year	305.00	117.69	122.40	120.76	122.45	0.000334	2.27	206.81	209.95	0.21

HEC-RAS Plan: Proposed (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Lower	83	50-Year	385.00	117.69	122.90	120.93	122.95	0.000309	2.37	246.36	213.74	0.20
Lower	83	100-Year	476.00	117.69	123.41	121.11	123.47	0.000291	2.49	287.50	219.21	0.20
Lower	83	500-Year	783.00	117.69	124.90	121.59	124.98	0.000260	2.82	406.92	246.73	0.20
Lower	3	10-Year	204.00	117.38	121.63	120.11	121.70	0.000470	2.40	114.11	205.29	0.24
Lower	3	25-Year	305.00	117.38	122.33	120.51	122.42	0.000470	2.74	149.07	219.08	0.25
Lower	3	50-Year	385.00	117.38	122.81	120.74	122.92	0.000471	2.97	173.29	231.28	0.25
Lower	3	100-Year	476.00	117.38	123.32	120.97	123.43	0.000471	3.20	198.47	240.63	0.26
Lower	3	500-Year	783.00	117.38	124.78	121.60	124.94	0.000471	3.82	271.48	252.54	0.27

HEC-RAS Plan: Proposed River: Mineway Brook Reach: South

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
South	474	10-Year	28.00	121.00	122.37	122.17	122.54	0.008838	3.43	8.83	12.41	0.67
South	474	25-Year	46.00	121.00	122.92	122.44	123.06	0.004435	3.08	16.87	16.77	0.50
South	474	50-Year	61.00	121.00	123.38	122.63	123.49	0.002571	2.80	25.48	21.42	0.40
South	474	100-Year	78.00	121.00	123.93	122.81	124.01	0.001386	2.53	39.23	28.63	0.31
South	474	500-Year	143.00	121.00	125.59	123.32	125.64	0.000440	2.11	97.04	116.96	0.19
South	400	10-Year	28.00	120.60	122.21	121.60	122.25	0.001793	1.68	16.71	18.23	0.31
South	400	25-Year	46.00	120.60	122.87	121.82	122.91	0.000823	1.53	31.10	26.17	0.22
South	400	50-Year	61.00	120.60	123.36	121.97	123.39	0.000516	1.47	45.43	57.77	0.19
South	400	100-Year	78.00	120.60	123.92	122.11	123.95	0.000332	1.40	63.58	89.33	0.16
South	400	500-Year	143.00	120.60	125.59	122.56	125.61	0.000165	1.39	128.04	185.15	0.12
South	300	10-Year	28.00	119.67	122.13	120.70	122.16	0.000554	1.29	22.22	89.03	0.18
South	300	25-Year	46.00	119.67	122.82	120.98	122.85	0.000393	1.38	39.98	118.71	0.16
South	300	50-Year	61.00	119.67	123.32	121.18	123.35	0.000316	1.41	54.51	126.68	0.15
South	300	100-Year	78.00	119.67	123.90	121.40	123.92	0.000247	1.41	71.13	135.97	0.14
South	300	500-Year	143.00	119.67	125.57	122.06	125.60	0.000175	1.56	119.59	151.17	0.12
South	200	10-Year	28.00	119.40	122.08	120.36	122.10	0.000482	1.26	22.29	40.60	0.16
South	200	25-Year	46.00	119.40	122.78	120.67	122.81	0.000439	1.43	35.99	117.99	0.16
South	200	50-Year	61.00	119.40	123.28	120.89	123.32	0.000367	1.49	48.67	123.79	0.15
South	200	100-Year	78.00	119.40	123.86	121.11	123.89	0.000295	1.51	63.16	130.18	0.14
South	200	500-Year	143.00	119.40	125.54	121.81	125.58	0.000220	1.69	105.06	140.29	0.13
South	100	10-Year	28.00	119.11	122.06	120.16	122.07	0.000157	0.84	44.04	113.77	0.10
South	100	25-Year	46.00	119.11	122.77	120.46	122.78	0.000116	0.88	77.32	117.74	0.09
South	100	50-Year	61.00	119.11	123.28	120.66	123.29	0.000097	0.90	101.35	119.04	0.09
South	100	100-Year	78.00	119.11	123.87	120.86	123.87	0.000080	0.91	128.73	120.52	0.08
South	100	500-Year	143.00	119.11	125.56	121.50	125.56	0.000018	0.54	484.06	124.83	0.04

Plan: Proposed Pantry Brook Lower RS: 485 Profile: 10-Year

E.G. US. (ft)	121.97	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	121.74	E.G. Elev (ft)	122.15	122.13
Q Total (cfs)	204.00	W.S. Elev (ft)	121.98	121.96
Q Bridge (cfs)	204.00	Crit W.S. (ft)	120.65	120.56
Q Weir (cfs)		Max Chl Dpth (ft)	3.62	3.73
Weir Sta Lft (ft)		Vel Total (ft/s)	3.27	3.20
Weir Sta Rgt (ft)		Flow Area (sq ft)	62.31	63.82
Weir Submerg		Froude # Chl	0.31	0.30
Weir Max Depth (ft)		Specif Force (cu ft)	109.63	114.95
Min El Weir Flow (ft)	130.96	Hydr Depth (ft)	2.50	2.56
Min El Prs (ft)	126.50	W.P. Total (ft)	29.80	29.75
Delta EG (ft)	0.07	Conv. Total (cfs)	5702.9	5677.8
Delta WS (ft)	0.04	Top Width (ft)	24.93	24.98
BR Open Area (sq ft)	138.48	Frctn Loss (ft)	0.02	0.02
BR Open Vel (ft/s)	3.27	C & E Loss (ft)	0.00	0.00
BR Sluice Coef		Shear Total (lb/sq ft)	0.17	0.17
BR Sel Method	Energy only	Power Total (lb/ft s)	0.55	0.55

Plan: Proposed Pantry Brook Lower RS: 485 Profile: 25-Year

E.G. US. (ft)	122.65	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	122.30	E.G. Elev (ft)	122.85	122.82
Q Total (cfs)	305.00	W.S. Elev (ft)	122.59	122.56
Q Bridge (cfs)	305.00	Crit W.S. (ft)	121.08	121.01
Q Weir (cfs)		Max Chl Dpth (ft)	4.23	4.33
Weir Sta Lft (ft)		Vel Total (ft/s)	3.96	3.89
Weir Sta Rgt (ft)		Flow Area (sq ft)	76.97	78.44
Weir Submerg		Froude # Chl	0.35	0.34
Weir Max Depth (ft)		Specif Force (cu ft)	169.42	175.21
Min El Weir Flow (ft)	130.96	Hydr Depth (ft)	3.29	3.35
Min El Prs (ft)	126.50	W.P. Total (ft)	31.78	31.72
Delta EG (ft)	0.09	Conv. Total (cfs)	7992.8	7689.2
Delta WS (ft)	0.03	Top Width (ft)	23.37	23.43
BR Open Area (sq ft)	138.48	Frctn Loss (ft)	0.02	0.02
BR Open Vel (ft/s)	3.96	C & E Loss (ft)	0.00	0.01
BR Sluice Coef		Shear Total (lb/sq ft)	0.22	0.24
BR Sel Method	Energy only	Power Total (lb/ft s)	0.87	0.94

Plan: Proposed Pantry Brook Lower RS: 485 Profile: 50-Year

E.G. US. (ft)	123.14	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	122.70	E.G. Elev (ft)	123.35	123.32
Q Total (cfs)	385.00	W.S. Elev (ft)	123.02	123.00
Q Bridge (cfs)	385.00	Crit W.S. (ft)	121.39	121.33
Q Weir (cfs)		Max Chl Dpth (ft)	4.66	4.77
Weir Sta Lft (ft)		Vel Total (ft/s)	4.43	4.36
Weir Sta Rgt (ft)		Flow Area (sq ft)	86.92	88.36
Weir Submerg		Froude # Chl	0.37	0.37
Weir Max Depth (ft)		Specif Force (cu ft)	221.17	227.28
Min El Weir Flow (ft)	130.96	Hydr Depth (ft)	3.91	3.96
Min El Prs (ft)	126.50	W.P. Total (ft)	33.20	33.13
Delta EG (ft)	0.12	Conv. Total (cfs)	9795.3	9173.5
Delta WS (ft)	0.02	Top Width (ft)	22.25	22.31
BR Open Area (sq ft)	138.48	Frctn Loss (ft)	0.03	0.02
BR Open Vel (ft/s)	4.43	C & E Loss (ft)	0.00	0.02

Plan: Proposed Pantry Brook Lower RS: 485 Profile: 50-Year (Continued)

BR Sluice Coef		Shear Total (lb/sq ft)	0.25	0.29
BR Sel Method	Energy only	Power Total (lb/ft s)	1.12	1.28

Plan: Proposed Pantry Brook Lower RS: 485 Profile: 100-Year

E.G. US. (ft)	123.71	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	123.18	E.G. Elev (ft)	123.88	123.85
Q Total (cfs)	476.00	W.S. Elev (ft)	123.48	123.45
Q Bridge (cfs)	476.00	Crit W.S. (ft)	121.71	121.66
Q Weir (cfs)		Max Chl Dpth (ft)	5.12	5.22
Weir Sta Lft (ft)		Vel Total (ft/s)	4.91	4.84
Weir Sta Rgt (ft)		Flow Area (sq ft)	96.92	98.30
Weir Submerg		Froude # Chl	0.39	0.39
Weir Max Depth (ft)		Specif Force (cu ft)	283.74	290.16
Min El Weir Flow (ft)	130.96	Hydr Depth (ft)	4.60	4.65
Min El Prs (ft)	126.50	W.P. Total (ft)	34.70	34.62
Delta EG (ft)	0.15	Conv. Total (cfs)	11469.2	10752.3
Delta WS (ft)	0.00	Top Width (ft)	21.07	21.14
BR Open Area (sq ft)	138.48	Frctn Loss (ft)	0.03	0.02
BR Open Vel (ft/s)	4.91	C & E Loss (ft)	0.00	0.05
BR Sluice Coef		Shear Total (lb/sq ft)	0.30	0.35
BR Sel Method	Energy only	Power Total (lb/ft s)	1.48	1.68

Plan: Proposed Pantry Brook Lower RS: 485 Profile: 500-Year

E.G. US. (ft)	125.32	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	124.54	E.G. Elev (ft)	125.47	125.41
Q Total (cfs)	783.00	W.S. Elev (ft)	124.79	124.71
Q Bridge (cfs)	783.00	Crit W.S. (ft)	122.60	122.55
Q Weir (cfs)		Max Chl Dpth (ft)	6.42	6.48
Weir Sta Lft (ft)		Vel Total (ft/s)	6.46	6.42
Weir Sta Rgt (ft)		Flow Area (sq ft)	121.23	121.97
Weir Submerg		Froude # Chl	0.46	0.47
Weir Max Depth (ft)		Specif Force (cu ft)	512.64	517.49
Min El Weir Flow (ft)	130.96	Hydr Depth (ft)	7.78	7.64
Min El Prs (ft)	126.50	W.P. Total (ft)	40.82	40.41
Delta EG (ft)	0.28	Conv. Total (cfs)	14682.8	14224.7
Delta WS (ft)	-0.04	Top Width (ft)	15.58	15.96
BR Open Area (sq ft)	138.48	Frctn Loss (ft)	0.05	0.03
BR Open Vel (ft/s)	6.46	C & E Loss (ft)	0.01	0.16
BR Sluice Coef		Shear Total (lb/sq ft)	0.53	0.57
BR Sel Method	Energy only	Power Total (lb/ft s)	3.41	3.67

Plan: Proposed   Pantry Brook   Lower RS: 505   Profile: 25-Year

E.G. Elev (ft)	122.65	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.35	Wt. n-Val.	0.039	0.028	0.033
W.S. Elev (ft)	122.30	Reach Len. (ft)	12.75	12.75	12.75
Crit W.S. (ft)	120.83	Flow Area (sq ft)	1.93	61.97	3.04
E.G. Slope (ft/ft)	0.001679	Area (sq ft)	1.93	61.97	3.04
Q Total (cfs)	305.00	Flow (cfs)	2.65	297.93	4.41
Top Width (ft)	21.09	Top Width (ft)	1.47	17.04	2.57
Vel Total (ft/s)	4.56	Avg. Vel. (ft/s)	1.37	4.81	1.45
Max Chl Dpth (ft)	3.94	Hydr. Depth (ft)	1.31	3.64	1.18
Conv. Total (cfs)	7444.4	Conv. (cfs)	64.7	7271.9	107.7
Length Wtd. (ft)	12.75	Wetted Per. (ft)	2.98	18.85	3.46
Min Ch El (ft)	118.36	Shear (lb/sq ft)	0.07	0.34	0.09
Alpha	1.09	Stream Power (lb/ft s)	0.09	1.66	0.13
Frctn Loss (ft)	0.02	Cum Volume (acre-ft)	1.94	0.74	1.67
C & E Loss (ft)	0.02	Cum SA (acres)	1.36	0.21	0.86

Plan: Proposed   Pantry Brook   Lower RS: 505   Profile: 50-Year

E.G. Elev (ft)	123.14	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.45	Wt. n-Val.	0.039	0.028	0.034
W.S. Elev (ft)	122.70	Reach Len. (ft)	12.75	12.75	12.75
Crit W.S. (ft)	121.19	Flow Area (sq ft)	2.52	68.73	4.14
E.G. Slope (ft/ft)	0.001867	Area (sq ft)	2.52	68.73	4.14
Q Total (cfs)	385.00	Flow (cfs)	4.25	373.40	7.35
Top Width (ft)	21.53	Top Width (ft)	1.49	17.04	3.00
Vel Total (ft/s)	5.11	Avg. Vel. (ft/s)	1.68	5.43	1.78
Max Chl Dpth (ft)	4.34	Hydr. Depth (ft)	1.69	4.03	1.38
Conv. Total (cfs)	8909.5	Conv. (cfs)	98.3	8641.1	170.2
Length Wtd. (ft)	12.75	Wetted Per. (ft)	3.38	18.85	4.04
Min Ch El (ft)	118.36	Shear (lb/sq ft)	0.09	0.43	0.12
Alpha	1.10	Stream Power (lb/ft s)	0.15	2.31	0.21
Frctn Loss (ft)	0.02	Cum Volume (acre-ft)	2.62	0.84	2.10
C & E Loss (ft)	0.03	Cum SA (acres)	1.45	0.21	0.91

APPENDIX 6.7:

SCOUR ANALYSIS

Existing and Proposed Contraction and Local Abutment Scour Calculations for 25-Year Design Return Frequency

Existing and Proposed Contraction and Local Abutment Scour Calculations for 50-Year Check Return Frequency

Particle Grain Size Analysis for Streambed

25-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Contraction Scour Analysis Calculations

25-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate the **channel contraction scour** experienced by the: **Existing Upstream Bridge Abutments**

Method:

Use HEC-18 Guidelines and the HEC-RAS model to solve for the total contraction scour for the 25-year storm. See Chapter 6 of HEC-18.

Assumptions:

If the critical velocity of the bed material is larger than the mean velocity ($V_c > V_{channel}$), then clear-water contraction scour will exist. If the critical velocity is less than the mean velocity ($V_c < V_{channel}$), then live-bed contraction scour will exist. If live-bed contraction scour is verified, Section 6.3, Note 8 of HEC-18 states that live-bed contraction scour may be limited by coarse sediments in the bed material armoring the bed. It is recommended to calculate both live-bed scour and clear-water scour depths and use the smaller calculated scour depth.

Calculations:

Calculate critical velocity within the channel

$$V_c = k y^{1/6} D_{50}^{1/3}$$

k =	11.17	for English Units
y =	3.64	Average Depth Upstream of the Bridge, ft
D_{50} =	0.1188	Particle size in a mixture of which 50 percent are smaller, mm
D_{50} =	0.00039	Particle size in a mixture of which 50 percent are smaller, ft
V_c =	1.01	ft/sec

$V_{channel}$ =	4.81	ft/sec, upstream of the bridge

Vc < Vchannel **Live-Bed Contraction Scour**

Calculate Clearwater Contraction Scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2} \right)^{3/7}$$

$Yc = Y_2 - Y_0$

K_u =	0.0077	for English Units
Q =	305	Discharge through the Bridge, cfs
D_m =	0.00049	Diameter of the smallest non transportable particle in the bed material, $1.25D_{50}$, ft
W =	12	Bottom Width of the Contracted Section, ft
Y_2 =	17.58	Average equilibrium depth in the contracted section after contraction scour, ft
Y_0 =	3.81	Average Channel Depth inside the bridge opening, ft

Y_c =	13.77	**Clearwater Contraction Scour, ft**

25-YR	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Contraction Scour Analysis Calculations

25-YR

Calculate Live-Bed Contraction Scour

$$\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1}$$

$Y_c = Y_2 - Y_0$

y_1 =	3.64	Average depth in the upstream main channel, ft
y_2 =	5.46	Average depth in the contracted section, ft
y_0 =	3.81	Existing depth in the contracted section before scour, ft
Q_1 =	298	Flow in the upstream channel transporting sediment, cfs
Q_2 =	305	Flow in the contracted channel, cfs
W_1 =	21	Bottom width of the upstream main channel that is transporting bed material, ft
W_2 =	12.0	Bottom width of the main channel in the contracted section less pier widths, ft
K_1 =	0.69	Exponent determined below

V_*/w	K_1	Mode of Bed Material Transport
<0.5	0.59	Mostly contact bed material discharge
0.5 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

V_* =	0.4193	Shear velocity in the upstream section, $(\tau_o/\rho)^{1/2} = (gy_1S_1)^{1/2}$, ft/s
w =	0.039	Fall velocity of bed material based on the D_{50}, ft/s (See Figure 6.8, next page)
g =	32.2	Acceleration of gravity, ft/s^2
S_1 =	0.0015	Slope of energy grade line of main channel, ft/ft
V_*/w =	10.7513	

Y_c = 1.65 **Live-Bed Contraction Scour, ft**

Conclusion

The Live-Bed Contraction Scour is less than the Clearwater Contraction Scour. Use the lesser value per HEC-18.

Scour depth = 1.65 ft

25-YR		Project:	Bruce Freeman Rail Trail over Pantry Brook		
		Job No.:	E2X81800	Location:	Sudbury, MA
		Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)		Checked By:	JRB	Date:	9/26/2018

Contraction Scour Analysis Calculations 25-YR

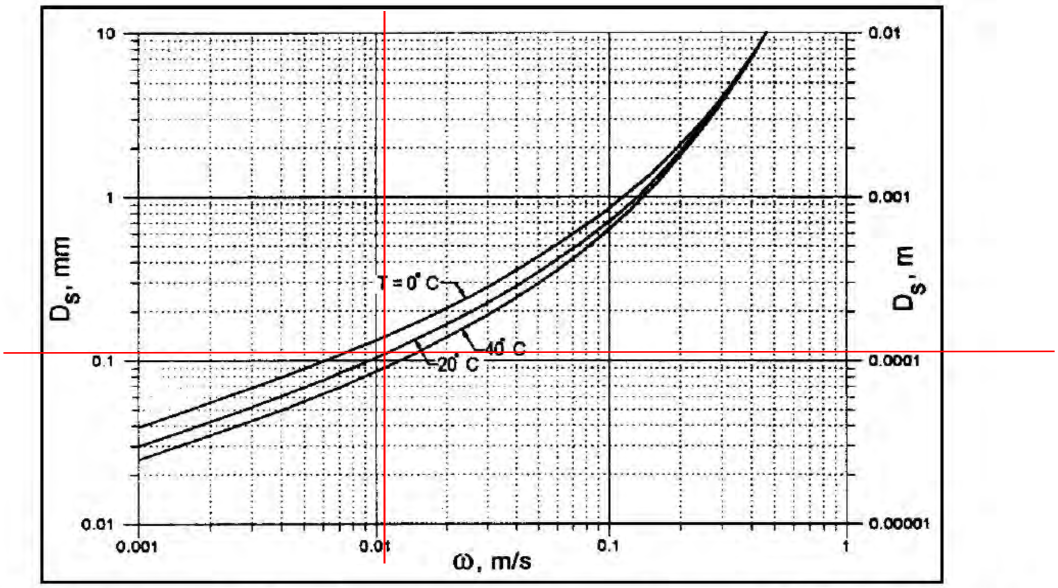


Figure 6.8. Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units.

Convert fall velocity from metric to US: 0.012 m/s = 0.039 ft/s

25-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

For Bruce Freeman Rail Trail Over Pantry Brook

25-YR

Objective:

Calculate the **total local abutment scour** experienced by the: Existing Southern Bridge Abutment

Method:

Use MassDOT LRFD Bridge Manual recommendations in accordinance with HEC-18 Guidelines and HEC-RAS to solve for the total local abutment scour for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

The existing abutment shape consists of vertical abutment walls with one 45 degree wingwall on the north abutment. The existing bridge span is 12'-0" near stream bed. The embankment angle is perpendicular to the flow.

Calculations:

Calculate Local Abutment Scour using the MassDOT Modified Froehlich Equation.

$$\frac{Y_S}{Y_a} = 2.27\, K_1\, K_2 \left(\frac{L'}{Y_a}\right)^{0.43} Fr^{0.61}$$

where:

K_1 =	1.00	Coefficient for abutment shape, Table 8.1 (see below)	
θ =	90.0	Angle of embankment to flow, Degrees	
K_2 =	1.00	Coefficient for angle of embankment to flow	
L' =	8.20	Length of active flow obstructed by the embankment, ft	
Q_e =		Flow obstructed by the abutment and approach embankments, cfs	
A_e =		Flow area of approach cross section obstructed by the emabkment, sf	
V_e =	1.45	Velocity of flow directly upstream of the abutment (Q_e/A_e), ft/s	(From HEC-RAS)
L =	8.20	Length of embankment projected normal to flow, ft	
Y_a =	1.18	Average Depth of flow in the floodplain directly upstream of the abutment, ft	
Fr =	0.17	Froude Number directly upstream of abutment = $V_e/(g{*}y_a)^{1/2}$	
g =	32.2	Acceleration of gravity, ft/s^2	

Check:

L / Y_a = 6.95 < 25, use Froehlich Equation

Scour Depth:

Y_S = 2.11 **Scour Depth, ft**

25-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

25-YR

Abutment Shape - Table 8.1:

Table 8.1. Abutment Shape Coefficients.	
Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

Angle of Embankment to Flow - Figure 7.5

$K_2 = (\theta/90)^{0.13}$ (see Figure 8.5 for definition of θ)
$\theta<90°$ if embankment points downstream
$\theta>90°$ if embankment points upstream

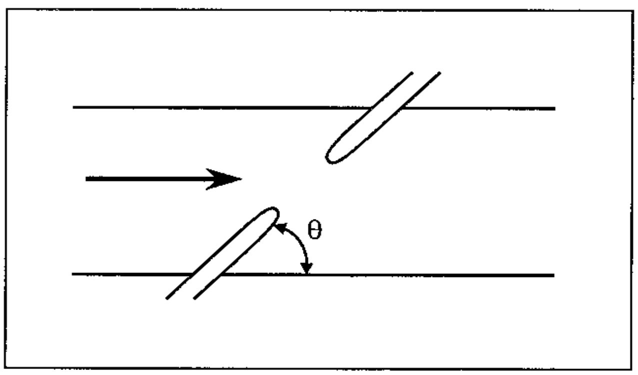


Figure 7.5. Orientation of embankment angle, θ, to the flow.

25-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

25-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate the **total local abutment scour** experienced by the: **Existing Norhern Bridge Abutment**

Method:

Use MassDOT LRFD Bridge Manual recommendations in accordinance with HEC-18 Guidelines and HEC-RAS to solve for the total local abutment scour for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

The existing abutment shape consists of vertical abutment walls with one 45 degree wingwall on the north abutment. The existing bridge span is 12'-0" near stream bed. The embankment angle is perpendicular to the flow.

Calculations:

Calculate Local Abutment Scour using the MassDOT Modified Froehlich Equation.

$$\frac{Y_S}{Y_a} = 2.27\ K_1\ K_2 \left(\frac{L'}{Y_a}\right)^{0.43} Fr^{0.61}$$

where:

K_1 =	0.82	Coefficient for abutment shape, Table 8.1 (see below)	
θ =	90.0	Angle of embankment to flow, Degrees	
K_2 =	1.00	Coefficient for angle of embankment to flow	
L' =	8.40	Length of active flow obstructed by the embankment, ft	
Q_e =		Flow obstructed by the abutment and approach embankments, cfs	
A_e =		Flow area of approach cross section obstructed by the emabkment, sf	
V_e =	1.37	Velocity of flow directly upstream of the abutment (Q_e/A_e), ft/s	(From HEC-RAS)
L =	8.40	Length of embankment projected normal to flow, ft	
Y_a =	1.31	Average Depth of flow in the floodplain directly upstream of the abutment, ft	
Fr =	0.20	Froude Number directly upstream of abutment = $V_e/(g*y_a)^{1/2}$	
g =	32.2	Acceleration of gravity, ft/s^2	

Check:

L / Y_a = 6.41 < 25, use Froehlich Equation

Scour Depth:

Y_S = 2.01 **Scour Depth, ft**

25-YR	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

25-YR

Abutment Shape - Table 8.1:

Table 8.1. Abutment Shape Coefficients.	
Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

Angle of Embankment to Flow - Figure 7.5

$K_2 = (\theta/90)^{0.13}$ (see Figure 8.5 for definition of θ)
θ<90° if embankment points downstream
θ>90° if embankment points upstream

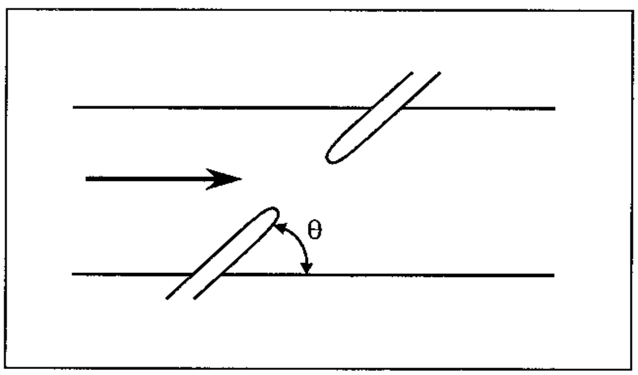


Figure 7.5. Orientation of embankment angle, θ, to the flow.

25-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Contraction Scour Analysis Calculations

25-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate the **channel contraction scour** experienced by the: **Proposed Upstream Bridge Abutments**

Method:

Use HEC-18 Guidelines and the HEC-RAS model to solve for the total contraction scour for the 25-year storm. See Chapter 6 of HEC-18.

Assumptions:

If the critical velocity of the bed material is larger than the mean velocity ($V_c > V_{channel}$), then clear-water contraction scour will exist. If the critical velocity is less than the mean velocity ($V_c < V_{channel}$), then live-bed contraction scour will exist. If live-bed contraction scour is verified, Section 6.3, Note 8 of HEC-18 states that live-bed contraction scour may be limited by coarse sediments in the bed material armoring the bed. It is recommended to calculate both live-bed scour and clear-water scour depths and use the smaller calculated scour depth.

Calculations:

Calculate critical velocity within the channel

$$V_c = k y^{1/6} D_{50}^{1/3}$$

k =	11.17	for English Units
y =	3.64	Average Depth Upstream of the Bridge, ft
D_{50} =	0.1188	Particle size in a mixture of which 50 percent are smaller, mm
D_{50} =	0.00039	Particle size in a mixture of which 50 percent are smaller, ft
V_c =	1.01	ft/sec
$V_{channel}$ =	4.81	ft/sec, upstream of the bridge

Vc < Vchannel **Live-Bed Contraction Scour**

Calculate Clearwater Contraction Scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2} \right)^{3/7}$$

$Yc = Y_2 - Y_0$

K_u =	0.0077	for English Units
Q =	305	Discharge through the Bridge, cfs
D_m =	0.00049	Diameter of the smallest non transportable particle in the bed material, $1.25D_{50}$, ft
W =	25.5	Bottom Width of the Contracted Section, ft
Y_2 =	9.21	Average equilibrium depth in the contracted section after contraction scour, ft
Y_0 =	3.29	Average Channel Depth inside the bridge opening, ft
Y_c =	5.92	**Clearwater Contraction Scour, ft**

25-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Contraction Scour Analysis Calculations

25-YR

Calculate Live-Bed Contraction Scour

$$\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1}$$

$Yc = Y_2 - Y_0$

y_1 =	3.64	Average depth in the upstream main channel, ft
y_2 =	3.43	Average depth in the contracted section, ft
y_0 =	3.29	Proposed depth in the contracted section before scour, ft
Q_1 =	294	Flow in the upstream channel transporting sediment, cfs
Q_2 =	305	Flow in the contracted channel, cfs
W_1 =	21	Bottom width of the upstream main channel that is transporting bed material, ft
W_2 =	24.0	Bottom width of the main channel in the contracted section less pier widths, ft
K_1 =	0.69	Exponent determined below

V_*/w	K_1	Mode of Bed Material Transport
<0.5	0.59	Mostly contact bed material discharge
0.5 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

V_* =	0.4193	Shear velocity in the upstream section, $(\tau_o/\rho)^{1/2} = (gy_1S_1)^{1/2}$, ft/s
w =	0.039	Fall velocity of bed material based on the D_{50}, ft/s (See Figure 6.8, next page)
g =	32.2	Acceleration of gravity, ft/s^2
S_1 =	0.0015	Slope of energy grade line of main channel, ft/ft
V_*/w =	10.7513	

Y_c =	0.14	**Live-Bed Contraction Scour, ft**

Conclusion

The Live-Bed Contraction Scour is less than the Clearwater Contraction Scour. Use the lesser value per HEC-18.

Scour depth = 0.14 ft

25-YR		Project:	Bruce Freeman Rail Trail over Pantry Brook		
		Job No.:	E2X81800	Location:	Sudbury, MA
		Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)		Checked By:	JRB	Date:	9/26/2018

Contraction Scour Analysis Calculations

25-YR

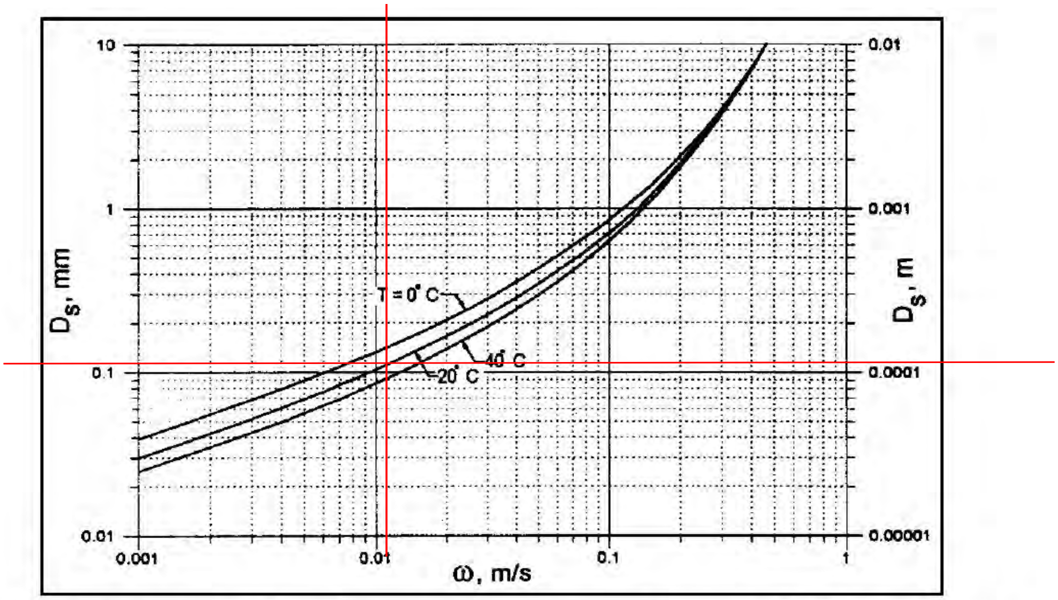


Figure 6.8. Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units.

Convert fall velocity from metric to US: 0.012 m/s = 0.039 ft/s

25-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

25-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate the **total local abutment scour** experienced by the: **Proposed Southern Bridge Abutment**

Method:

Use MassDOT LRFD Bridge Manual recommendations in accordinance with HEC-18 Guidelines and HEC-RAS to solve for the total local abutment scour for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

The proposed bridge replacement consists of a conspan arch with 45 degree wingwalls. The existing abutment will be removed down to streambed level and footings for the new structure will be located behind the existing abutments with a stone riprap slope placed on the new footings. The existing proposed span is 34'-0" near stream bed. The embankment angle is perpendicular to the flow.

Calculations:

Calculate Local Abutment Scour using the MassDOT Modified Froehlich Equation.

$$\frac{Y_S}{Y_a} = 2.27\ K_1\ K_2 \left(\frac{L'}{Y_a}\right)^{0.43} Fr^{0.61}$$

where:

K_1 =	0.82	Coefficient for abutment shape, Table 8.1 (see below)
θ =	90.0	Angle of embankment to flow, Degrees
K_2 =	1.00	Coefficient for angle of embankment to flow
L' =	1.90	Length of active flow obstructed by the embankment, ft
Q_e =		Flow obstructed by the abutment and approach embankments, cfs
A_e =		Flow area of approach cross section obstructed by the emabkment, sf
V_e =	1.45	Velocity of flow directly upstream of the abutment (Q_e/A_e), ft/s
L =	1.90	Length of embankment projected normal to flow, ft
Y_a =	1.18	Average Depth of flow in the floodplain directly upstream of the abutment, ft
Fr =	0.17	Froude Number directly upstream of abutment = $V_e/(g*y_a)^{1/2}$
g =	32.2	Acceleration of gravity, ft/s^2

Check:

L / Y_a = 1.61 < 25, use Froehlich Equation

Scour Depth:

Y_S = 0.92 **Scour Depth, ft**

25-YR	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

25-YR

Abutment Shape - Table 8.1:

Table 8.1. Abutment Shape Coefficients.

Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

Angle of Embankment to Flow - Figure 7.5

$K_2 = (\theta/90)^{0.13}$ (see Figure 8.5 for definition of θ)

$\theta<90°$ if embankment points downstream

$\theta>90°$ if embankment points upstream

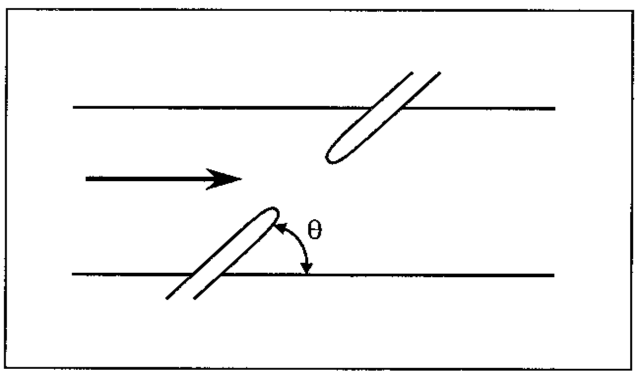


Figure 7.5. Orientation of embankment angle, θ, to the flow.

25-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

25-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate the **total local abutment scour** experienced by the: Proposed Northern Bridge Abutment

Method:

Use MassDOT LRFD Bridge Manual recommendations in accordinance with HEC-18 Guidelines and HEC-RAS to solve for the total local abutment scour for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

The proposed bridge replacement consists of a conspan arch with 45 degree wingwalls. The existing abutment will be removed down to streambed level and footings for the new structure will be located behind the existing abutments with a stone riprap slope placed on the new footings. The existing proposed span is 34'-0" near stream bed. The embankment angle is perpendicular to the flow.

Calculations:

Calculate Local Abutment Scour using the MassDOT Modified Froehlich Equation.

$$\frac{Y_S}{Y_a} = 2.27\, K_1\, K_2 \left(\frac{L'}{Y_a}\right)^{0.43} Fr^{0.61}$$

where:

K_1 =	0.82	Coefficient for abutment shape, Table 8.1 (see below)
θ =	90.0	Angle of embankment to flow, Degrees
K_2 =	1.00	Coefficient for angle of embankment to flow
L' =	1.70	Length of active flow obstructed by the embankment, ft
Q_e =		Flow obstructed by the abutment and approach embankments, cfs
A_e =		Flow area of approach cross section obstructed by the emabkment, sf
V_e =	1.38	Velocity of flow directly upstream of the abutment (Q_e/A_e), ft/s
L =	1.70	Length of embankment projected normal to flow, ft
Y_a =	1.31	Average Depth of flow in the floodplain directly upstream of the abutment, ft
Fr =	0.20	Froude Number directly upstream of abutment = $V_e/(g*y_a)^{1/2}$
g =	32.2	Acceleration of gravity, ft/s^2

Check:

L / Y_a = 1.30 < 25, use Froehlich Equation

Scour Depth:

Y_S = 1.01 **Scour Depth, ft**

25-YR	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

25-YR

Abutment Shape - Table 8.1:

Table 8.1. Abutment Shape Coefficients.	
Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

Angle of Embankment to Flow - Figure 7.5

$K_2 = (\theta/90)^{0.13}$ (see Figure 8.5 for definition of θ)

$\theta<90°$ if embankment points downstream

$\theta>90°$ if embankment points upstream

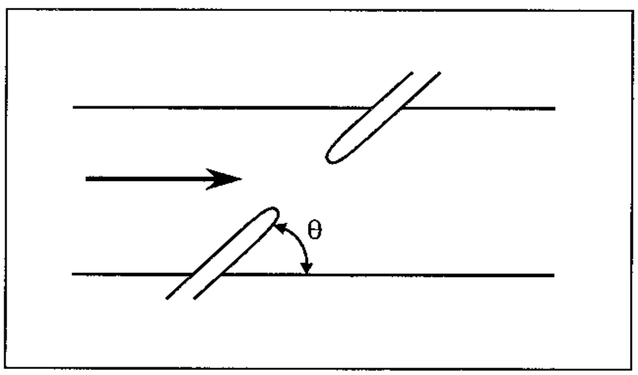


Figure 7.5. Orientation of embankment angle, θ, to the flow.

50-YR	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Contraction Scour Analysis Calculations

50-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate the **channel contraction scour** experienced by the: **Existing Upstream Bridge Abutments**

Method:

Use HEC-18 Guidelines and the HEC-RAS model to solve for the total contraction scour for the 25-year storm. See Chapter 6 of HEC-18.

Assumptions:

If the critical velocity of the bed material is larger than the mean velocity ($V_c > V_{channel}$), then clear-water contraction scour will exist. If the critical velocity is less than the mean velocity ($V_c < V_{channel}$), then live-bed contraction scour will exist. If live-bed contraction scour is verified, Section 6.3, Note 8 of HEC-18 states that live-bed contraction scour may be limited by coarse sediments in the bed material armoring the bed. It is recommended to calculate both live-bed scour and clear-water scour depths and use the smaller calculated scour depth.

Calculations:

Calculate critical velocity within the channel

$$V_c = k y^{1/6} D_{50}^{1/3}$$

k =	11.17	for English Units
y =	4.03	Average Depth Upstream of the Bridge, ft
D_{50} =	0.1188	Particle size in a mixture of which 50 percent are smaller, mm
D_{50} =	0.00039	Particle size in a mixture of which 50 percent are smaller, ft
V_c =	1.03	ft/sec
$V_{channel}$ =	5.43	ft/sec, upstream of the bridge

Vc < Vchannel **Live-Bed Contraction Scour**

Calculate Clearwater Contraction Scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2} \right)^{3/7}$$

$Yc = Y_2 - Y_0$

K_u =	0.0077	for English Units
Q =	385	Discharge through the Bridge, cfs
D_m =	0.00049	Diameter of the smallest non transportable particle in the bed material, $1.25D_{50}$, ft
W =	12	Bottom Width of the Contracted Section, ft
Y_2 =	21.46	Average equilibrium depth in the contracted section after contraction scour, ft
Y_0 =	4.18	Average Channel Depth inside the bridge opening, ft
Y_c =	17.28	**Clearwater Contraction Scour, ft**

50-YR	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Contraction Scour Analysis Calculations

50-YR

Calculate Live-Bed Contraction Scour

$$\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1}$$

$Yc = Y_2 - Y_0$

y_1 =	4.03	Average depth in the upstream main channel, ft
y_2 =	6.09	Average depth in the contracted section, ft
y_0 =	4.18	Existing depth in the contracted section before scour, ft
Q_1 =	373	Flow in the upstream channel transporting sediment, cfs
Q_2 =	385	Flow in the contracted channel, cfs
W_1 =	21	Bottom width of the upstream main channel that is transporting bed material, ft
W_2 =	12.0	Bottom width of the main channel in the contracted section less pier widths, ft
K_1 =	0.69	Exponent determined below

V_*/w	K_1	Mode of Bed Material Transport
<0.5	0.59	Mostly contact bed material discharge
0.5 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

V_* =	0.44119	Shear velocity in the upstream section, $(\tau_o/\rho)^{1/2} = (gy_1S_1)^{1/2}$, ft/s
w =	0.039	Fall velocity of bed material based on the D_{50}, ft/s (See Figure 6.8, next page)
g =	32.2	Acceleration of gravity, ft/s^2
S_1 =	0.0015	Slope of energy grade line of main channel, ft/ft
V_*/w =	11.3126	

Y_c = 1.91 **Live-Bed Contraction Scour, ft**

Conclusion

The Live-Bed Contraction Scour is less than the Clearwater Contraction Scour. Use the lesser value per HEC-18.

Scour depth = 1.91 ft

50-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Contraction Scour Analysis Calculations

50-YR

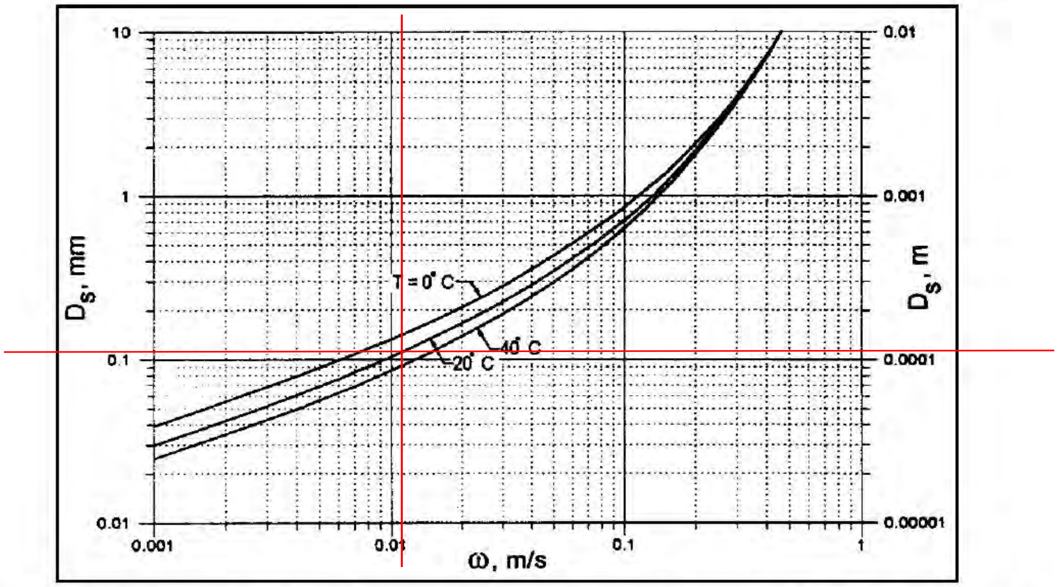


Figure 6.8. Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units.

Convert fall velocity from metric to US: 0.012 m/s = 0.039 ft/s

50-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

50-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate the **total local abutment scour** experienced by the: **Existing Southern Bridge Abutment**

Method:

Use MassDOT LRFD Bridge Manual recommendations in accordinance with HEC-18 Guidelines and HEC-RAS to solve for the total local abutment scour for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

The existing abutment shape consists of vertical abutment walls with one 45 degree wingwall on the north abutment. The existing bridge span is 12'-0" near stream bed. The embankment angle is perpendicular to the flow.

Calculations:

Calculate Local Abutment Scour using the MassDOT Modified Froehlich Equation.

$$\frac{Y_S}{Y_a} = 2.27\, K_1\, K_2 \left(\frac{L'}{Y_a}\right)^{0.43} Fr^{0.61}$$

where:

K_1 =	1.00	Coefficient for abutment shape, Table 8.1 (see below)
θ =	90.0	Angle of embankment to flow, Degrees
K_2 =	1.00	Coefficient for angle of embankment to flow
L' =	8.20	Length of active flow obstructed by the embankment, ft
Q_e =		Flow obstructed by the abutment and approach embankments, cfs
A_e =		Flow area of approach cross section obstructed by the emabkment, sf
V_e =	1.78	Velocity of flow directly upstream of the abutment (Q_e/A_e), ft/s (From HEC-RAS)
L =	8.20	Length of embankment projected normal to flow, ft
Y_a =	1.38	Average Depth of flow in the floodplain directly upstream of the abutment, ft
Fr =	0.18	Froude Number directly upstream of abutment = $V_e/(g*y_a)^{1/2}$
g =	32.2	Acceleration of gravity, ft/s^2

Check:

L / Y_a = 5.94 < 25, use Froehlich Equation

Scour Depth:

Y_S = 2.39 **Scour Depth, ft**

50-YR		Project:	Bruce Freeman Rail Trail over Pantry Brook		
		Job No.:	E2X81800	Location:	Sudbury, MA
		Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)		Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

50-YR

Abutment Shape - Table 8.1:

Table 8.1. Abutment Shape Coefficients.	
Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

Angle of Embankment to Flow - Figure 7.5

$K_2 = (\theta/90)^{0.13}$ (see Figure 8.5 for definition of θ)

$\theta<90°$ if embankment points downstream

$\theta>90°$ if embankment points upstream

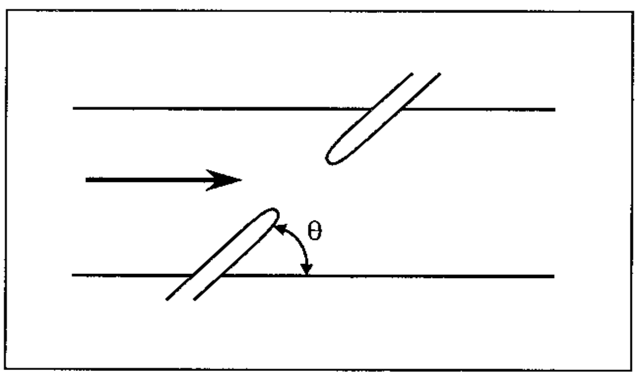


Figure 7.5. Orientation of embankment angle, θ, to the flow.

50-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

50-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate the **total local abutment scour** experienced by the: Existing Northern Bridge Abutment

Method:

Use MassDOT LRFD Bridge Manual recommendations in accordinance with HEC-18 Guidelines and HEC-RAS to solve for the total local abutment scour for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

The existing abutment shape consists of vertical abutment walls with one 45 degree wingwall on the north abutment. The existing bridge span is 12'-0" near stream bed. The embankment angle is perpendicular to the flow.

Calculations:

Calculate Local Abutment Scour using the MassDOT Modified Froehlich Equation.

$$\frac{Y_S}{Y_a} = 2.27\ K_1\ K_2 \left(\frac{L'}{Y_a}\right)^{0.43} Fr^{0.61}$$

where:

K_1 =	0.82	Coefficient for abutment shape, Table 8.1 (see below)
θ =	90.0	Angle of embankment to flow, Degrees
K_2 =	1.00	Coefficient for angle of embankment to flow
L' =	8.40	Length of active flow obstructed by the embankment, ft
Q_e =		Flow obstructed by the abutment and approach embankments, cfs
A_e =		Flow area of approach cross section obstructed by the emabkment, sf
V_e =	1.68	Velocity of flow directly upstream of the abutment (Q_e/A_e), ft/s (From HEC-RAS)
L =	8.40	Length of embankment projected normal to flow, ft
Y_a =	1.69	Average Depth of flow in the floodplain directly upstream of the abutment, ft
Fr =	0.23	Froude Number directly upstream of abutment = $V_e/(g*y_a)^{1/2}$
g =	32.2	Acceleration of gravity, ft/s^2

Check:

L / Y_a = 4.97 < 25, use Froehlich Equation

Scour Depth:

Y_S = 2.56 **Scour Depth, ft**

50-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

50-YR

Abutment Shape - Table 8.1:

Table 8.1. Abutment Shape Coefficients.	
Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

Angle of Embankment to Flow - Figure 7.5

$K_2 = (\theta/90)^{0.13}$ (see Figure 8.5 for definition of θ)

$\theta<90°$ if embankment points downstream

$\theta>90°$ if embankment points upstream

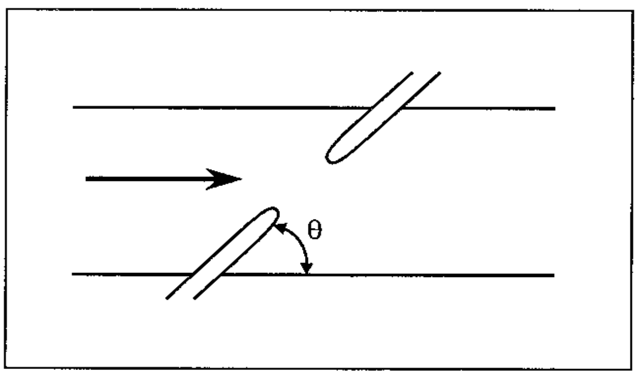


Figure 7.5. Orientation of embankment angle, θ, to the flow.

50-YR	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Contraction Scour Analysis Calculations

50-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate the **channel contraction scour** experienced by the: **Proposed Upstream Bridge Abutments**

Method:

Use HEC-18 Guidelines and the HEC-RAS model to solve for the total contraction scour for the 25-year storm. See Chapter 6 of HEC-18.

Assumptions:

If the critical velocity of the bed material is larger than the mean velocity ($V_c > V_{channel}$), then clear-water contraction scour will exist. If the critical velocity is less than the mean velocity ($V_c < V_{channel}$), then live-bed contraction scour will exist. If live-bed contraction scour is verified, Section 6.3, Note 8 of HEC-18 states that live-bed contraction scour may be limited by coarse sediments in the bed material armoring the bed. It is recommended to calculate both live-bed scour and clear-water scour depths and use the smaller calculated scour depth.

Calculations:

Calculate critical velocity within the channel

$$V_c = k y^{1/6} D_{50}^{1/3}$$

k =	11.17	for English Units
y =	4.03	Average Depth Upstream of the Bridge, ft
D_{50} =	0.1188	Particle size in a mixture of which 50 percent are smaller, mm
D_{50} =	0.00039	Particle size in a mixture of which 50 percent are smaller, ft
V_c =	1.03	ft/sec
$V_{channel}$ =	5.43	ft/sec, upstream of the bridge

Vc < Vchannel **Live-Bed Contraction Scour**

Calculate Clearwater Contraction Scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2} \right)^{3/7}$$

$Yc = Y_2 - Y_0$

K_u =	0.0077	for English Units
Q =	385	Discharge through the Bridge, cfs
D_m =	0.00049	Diameter of the smallest non transportable particle in the bed material, $1.25D_{50}$, ft
W =	25.5	Bottom Width of the Contracted Section, ft
Y_2 =	11.25	Average equilibrium depth in the contracted section after contraction scour, ft
Y_0 =	3.91	Average Channel Depth inside the bridge opening, ft
Y_c =	7.34	**Clearwater Contraction Scour, ft**

50-YR

Project:	Bruce Freeman Rail Trail over Pantry Brook		
Job No.:	E2X81800	Location:	Sudbury, MA
Calced By:	AMS	Date:	9/24/2018
Checked By:	JRB	Date:	9/26/2018

(Type input values into the shaded boxes)

Contraction Scour Analysis Calculations

50-YR

Calculate Live-Bed Contraction Scour

$$\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1}$$

$Y_C = Y_2 - Y_0$

y_1 =	4.03	Average depth in the upstream main channel, ft
y_2 =	3.78	Average depth in the contracted section, ft
y_0 =	3.91	Proposed depth in the contracted section before scour, ft
Q_1 =	373	Flow in the upstream channel transporting sediment, cfs
Q_2 =	385	Flow in the contracted channel, cfs
W_1 =	21	Bottom width of the upstream main channel that is transporting bed material, ft
W_2 =	24.0	Bottom width of the main channel in the contracted section less pier widths, ft
K_1 =	0.69	Exponent determined below

V_*/w	K_1	Mode of Bed Material Transport
<0.5	0.59	Mostly contact bed material discharge
0.5 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

V_* =	0.44119	Shear velocity in the upstream section, $(\tau_o/\rho)^{1/2} = (gy_1S_1)^{1/2}$, ft/s
w =	0.039	Fall velocity of bed material based on the D_{50}, ft/s (See Figure 6.8, next page)
g =	32.2	Acceleration of gravity, ft/s^2
S_1 =	0.0015	Slope of energy grade line of main channel, ft/ft
V_*/w =	11.3126	

Y_c =	-0.13	**Live-Bed Contraction Scour, ft**

Conclusion

The Live-Bed Contraction Scour is less than the Clearwater Contraction Scour. Use the lesser value per HEC-18.

Scour depth = 0.0 ft

50-YR	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Contraction Scour Analysis Calculations

50-YR

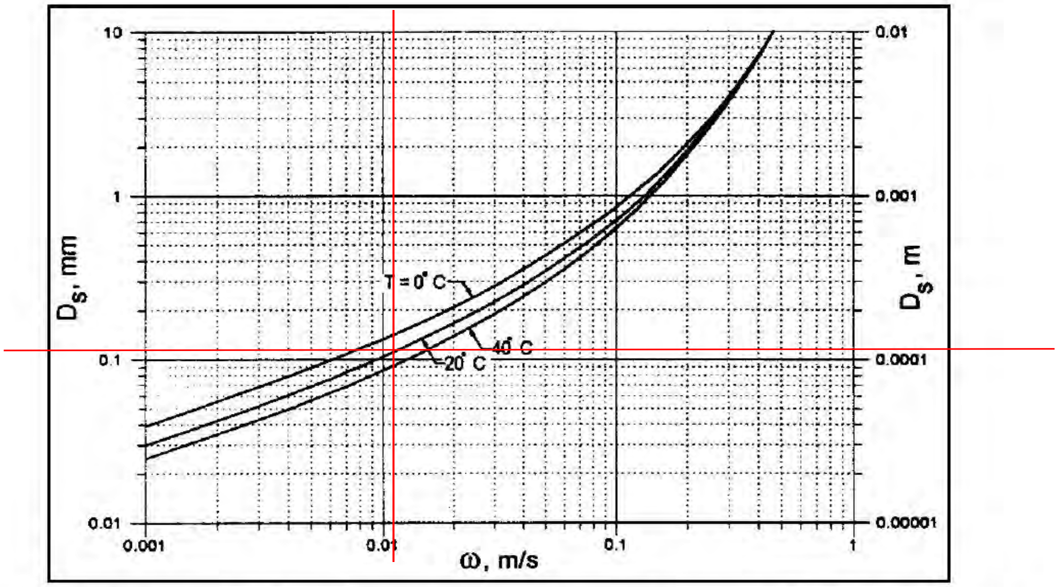


Figure 6.8. Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units.

Convert fall velocity from metric to US: 0.012 m/s = 0.039 ft/s

50-YR					
	Project:	Bruce Freeman Rail Trail over Pantry Brook			
	Job No.:	E2X81800	Location:	Sudbury, MA	
	Calced By:	AMS	Date:	9/24/2018	
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018	

Local Abutment Scour Analysis Calculations

50-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate the **total local abutment scour** experienced by the: Proposed Southern Bridge Abutment

Method:

Use MassDOT LRFD Bridge Manual recommendations in accordinance with HEC-18 Guidelines and HEC-RAS to solve for the total local abutment scour for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

The proposed bridge replacement consists of a conspan arch with 45 degree wingwalls. The existing abutment will be removed down to streambed level and footings for the new structure will be located behind the existing abutments with a stone riprap slope placed on the new footings. The existing proposed span is 34'-0" near stream bed. The embankment angle is perpendicular to the flow.

Calculations:

Calculate Local Abutment Scour using the MassDOT Modified Froehlich Equation.

$$\frac{Y_S}{Y_a} = 2.27\, K_1\, K_2 \left(\frac{L'}{Y_a}\right)^{0.43} Fr^{0.61}$$

where:

K_1 =	0.82	Coefficient for abutment shape, Table 8.1 (see below)
θ =	90.0	Angle of embankment to flow, Degrees
K_2 =	1.00	Coefficient for angle of embankment to flow
L' =	1.90	Length of active flow obstructed by the embankment, ft
Q_e =		Flow obstructed by the abutment and approach embankments, cfs
A_e =		Flow area of approach cross section obstructed by the emabkment, sf
V_e =	1.78	Velocity of flow directly upstream of the abutment (Q_e/A_e), ft/s
L =	1.90	Length of embankment projected normal to flow, ft
Y_a =	1.38	Average Depth of flow in the floodplain directly upstream of the abutment, ft
Fr =	0.18	Froude Number directly upstream of abutment = $V_e/(g*y_a)^{1/2}$
g =	32.2	Acceleration of gravity, ft/s^2

Check:

L / Y_a = 1.38 < 25, use Froehlich Equation

Scour Depth:

Y_S = 1.04 **Scour Depth, ft**

50-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

50-YR

Abutment Shape - Table 8.1:

Table 8.1. Abutment Shape Coefficients.	
Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

Angle of Embankment to Flow - Figure 7.5

$K_2 = (\theta/90)^{0.13}$ (see Figure 8.5 for definition of θ)
$\theta<90°$ if embankment points downstream
$\theta>90°$ if embankment points upstream

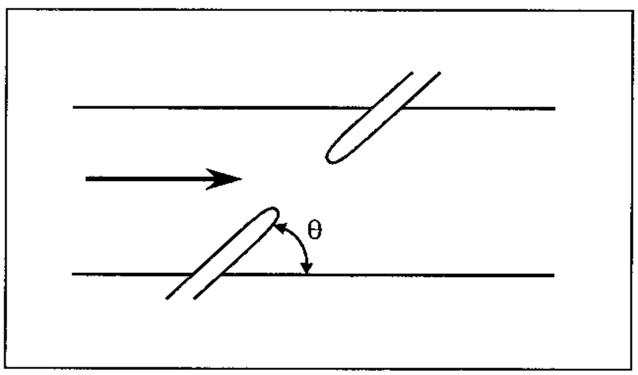


Figure 7.5. Orientation of embankment angle, θ, to the flow.

50-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

50-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate the **total local abutment scour** experienced by the: Proposed Northern Bridge Abutment

Method:

Use MassDOT LRFD Bridge Manual recommendations in accordinance with HEC-18 Guidelines and HEC-RAS to solve for the total local abutment scour for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

The proposed bridge replacement consists of a conspan arch with 45 degree wingwalls. The existing abutment will be removed down to streambed level and footings for the new structure will be located behind the existing abutments with a stone riprap slope placed on the new footings. The existing proposed span is 34'-0" near stream bed. The embankment angle is perpendicular to the flow.

Calculations:

Calculate Local Abutment Scour using the MassDOT Modified Froehlich Equation.

$$\frac{Y_S}{Y_a} = 2.27\, K_1\, K_2 \left(\frac{L'}{Y_a}\right)^{0.43} Fr^{0.61}$$

where:

K_1 =	0.82	Coefficient for abutment shape, Table 8.1 (see below)
θ =	90.0	Angle of embankment to flow, Degrees
K_2 =	1.00	Coefficient for angle of embankment to flow
L' =	1.70	Length of active flow obstructed by the embankment, ft
Q_e =		Flow obstructed by the abutment and approach embankments, cfs
A_e =		Flow area of approach cross section obstructed by the emabkment, sf
V_e =	1.68	Velocity of flow directly upstream of the abutment (Q_e/A_e), ft/s
L =	1.70	Length of embankment projected normal to flow, ft
Y_a =	1.69	Average Depth of flow in the floodplain directly upstream of the abutment, ft
Fr =	0.23	Froude Number directly upstream of abutment = $V_e/(g*y_a)^{1/2}$
g =	32.2	Acceleration of gravity, ft/s^2

Check:

L / Y_a = 1.01 < 25, use Froehlich Equation

Scour Depth:

Y_S = **1.29** **Scour Depth, ft**

50-YR	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	9/24/2018
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	9/26/2018

Local Abutment Scour Analysis Calculations

50-YR

Abutment Shape - Table 8.1:

Table 8.1. Abutment Shape Coefficients.	
Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

Angle of Embankment to Flow - Figure 7.5

$K_2 = (\theta/90)^{0.13}$ (see Figure 8.5 for definition of θ)

$\theta<90°$ if embankment points downstream

$\theta>90°$ if embankment points upstream

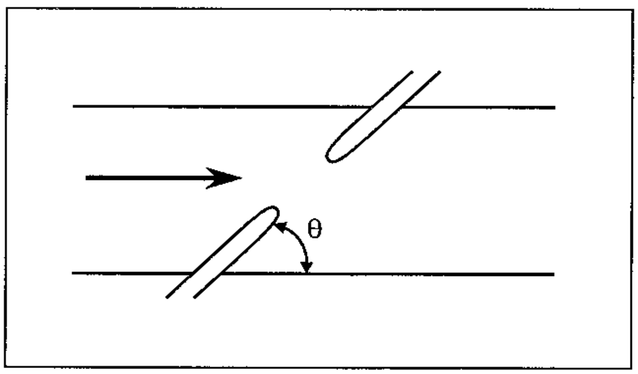
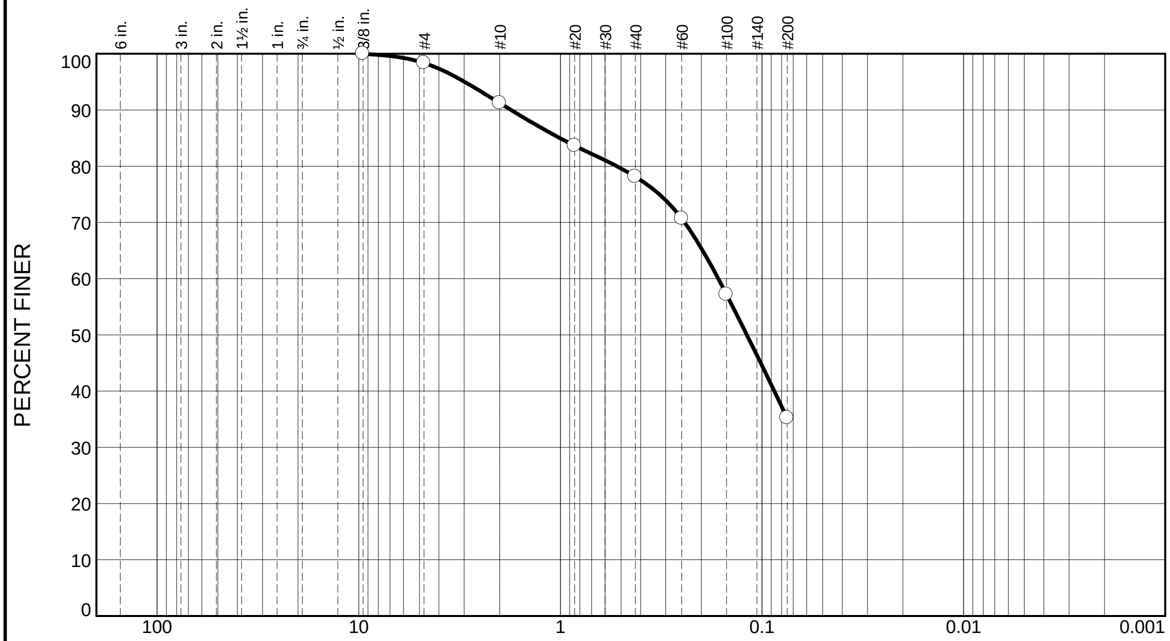


Figure 7.5. Orientation of embankment angle, θ, to the flow.

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.6	7.2	13.1	42.9	35.2	

Test Results (D6913 & ASTM D 1140)			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
0.375"	100.0		
#4	98.4		
#10	91.2		
#20	83.7		
#40	78.1		
#60	70.7		
#100	57.2		
#200	35.2		

* (no specification provided)

Material Description

Dark Brown Organic silty sand

Atterberg Limits (ASTM D 4318)

PL= LL= PI=

Classification

USCS (D 2487)= SC AASHTO (M 145)= A-2-4(0)

Coefficients

D_{90}= 1.7575 D_{85}= 1.0043 D_{60}= 0.1648
D_{50}= 0.1188 D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

Sample visually classified as plastic. Sample rolled to 1/8".

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

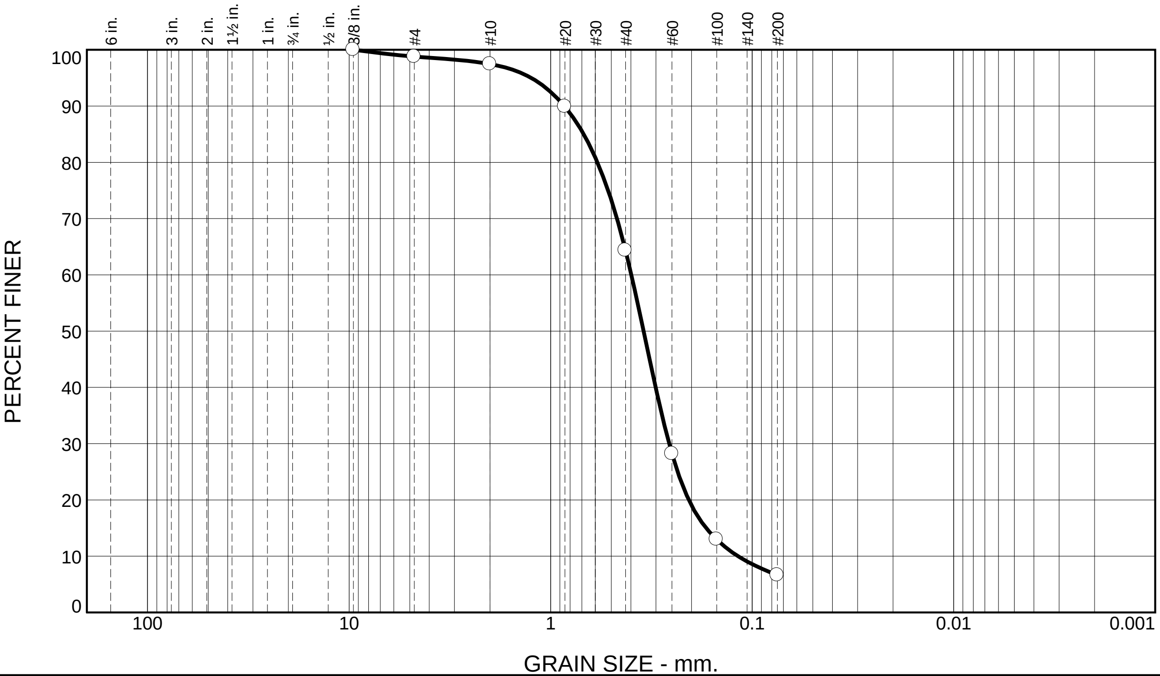
Source of Sample: BB-101 **Depth:** 16-18' **Date Sampled:** 08.16.19
Sample Number: S9

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1795

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.2	1.3	33.2	57.7	6.6	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
0.375"	100.0		
#4	98.8		
#10	97.5		
#20	89.9		
#40	64.3		
#60	28.2		
#100	13.0		
#200	6.6		

* (no specification provided)

Material Description

Brown poorly graded sand with silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-3

Coefficients

D_{90}= 0.8545 D_{85}= 0.6850 D_{60}= 0.3978
D_{50}= 0.3457 D_{30}= 0.2581 D_{15}= 0.1693
D_{10}= 0.1175 C_u= 3.39 C_c= 1.43

Remarks

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

Source of Sample: BB-102A **Depth:** 16-18' **Date Sampled:** 08.20.19
Sample Number: S9

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1800

APPENDIX 6.8:

RIPRAP PROTECTION CALCULATIONS

JACOBS

2 EXECUTIVE PARK DRIVE
BEDFORD, NH
603-666-7181

JOB NO.	E2X81800 - Bruce Freeman Rail Trail over Pantry Brook
SHEET NO.	1 OF 1
CALCULATED BY:	AMS DATE: 9/23/2019
CHECKED BY:	JRB DATE: 9/26/2019

Objective

Use the Federal Highway Administration's HEC-23, Sizing Rock Rip-rap at Abutments, to calculate the size of rip-rap, d_{50}, at the proposed abutment.

Method

Use results from the 50-year proposed conditions HEC-RAS analysis to calculate the d_{50}.

V = Average velocity in the contracted section	4.39	ft/sec		
y = Depth of Flow in the Contracted Section	3.86	ft		
S_s = Specific Gravity of Rock Rip-Rap	2.65			
g = Gravitational Acceleration	32.2	ft/sec^2		
Froude Number = $V/(gy)^{1/2}$	0.39		Subcritical	Use ≤ 0.80
K = Constant: 1.02 for Vertical Wall Abutment 0.89 for spill-through abutment	0.89			
d_{50} = Stone diameter	0.32	ft		
	3.87	in		

If Froude Number is ≤ 0.80:

$$d_{50}=\left(\frac{K}{(S_s-1)}\left[\frac{V^2}{gy}\right]\right)y$$

If Froude Number is > 0.80:

$$\frac{D_{50}}{y}=\frac{K}{(S_s-1)}\left[\frac{V^2}{gy}\right]^{0.14}$$

Results

Use d_{50}	3.88 in

Thickness (	7.76 in

=2 times d_{50}

Reference

Hydraulic Engineering Circular No. 23, Publication No. FHWA NHI 01-003, "Bridge Scour and Stream Instability Countermeasures," Second Edition, March 2001