

# Hydrologic and Hydraulic Report



## Pearl Street/Elmer Brook Culvert Replacement South Hadley, MA

December 19, 2022



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20150214.B40

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# 1 Executive Summary

The Town of South Hadley has been awarded a FY23 Massachusetts Division of Ecological Restoration (DER) Culvert Replacement Municipal Assistance Grant to complete field data collection and design for a replacement crossing at Pearl Street and Elmer Brook. The crossing has been identified as among the top 5% of crossings prioritized for replacement by the Mass Wildlife Climate Action Tool and is located along a stream that is mapped as a coldwater fishery resource. Further, due to the observed field conditions, limited hydraulic capacity of the culvert, and a known history of flooding at this location, the crossing was identified as a top 10 priority crossing for the Town during their FY21 MVP Action Grant to assess and prioritize culverts for replacement Town-wide. The purpose of this report is to summarize the hydrologic and hydraulic analyses completed to size and design a new stream crossing based on Massachusetts Department of Transportation (MassDOT) Chapter 85 bridge replacement standards and Massachusetts Stream Crossing Standards while also addressing future climate conditions using the guidelines created by the Resilient Massachusetts Action Team (RMAT).

The existing condition of the stream crossing consists of one six-foot round corrugated metal pipe with severe deficiencies. The pipe severely constricts the stream's bankfull width and has a cascade/free fall condition at the outlet. These conditions have resulted in the formation of a large scour pool approximately 40 feet across and 4-6 feet deep downstream of the culvert. The proposed improvements will replace the existing pipe with a 16-foot span by 6-foot rise open-bottom three-sided frame that is designed for both current and predicted climatic condition peak flows. The site is identified on the USGS Site Location Map, Figure 1.

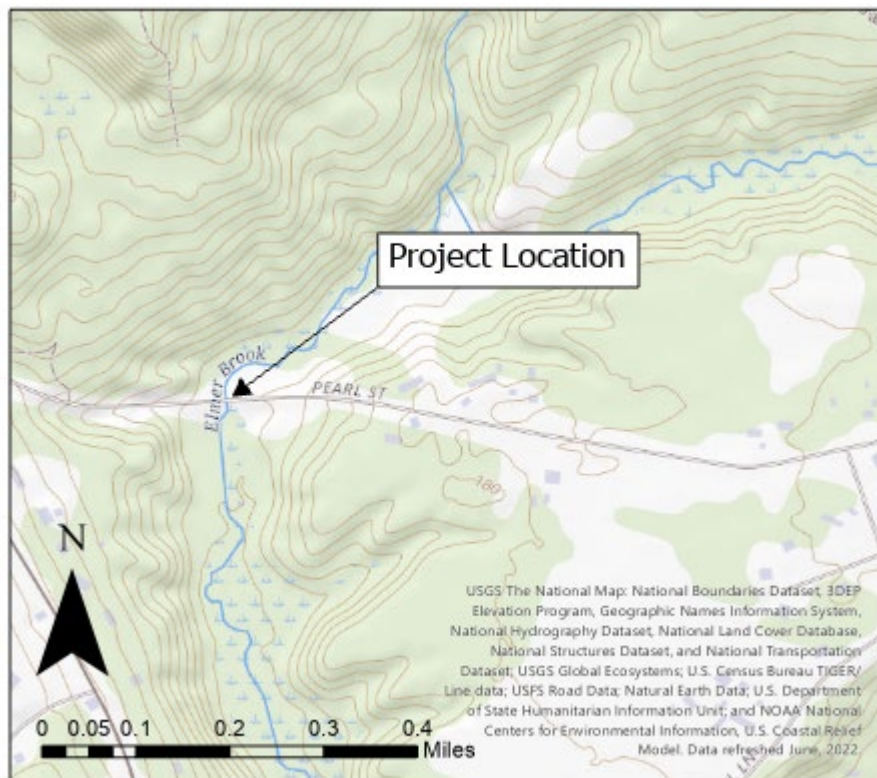


Figure 1. USGS Site Location Map

## 2 Project Description

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### 2.1 Existing Conditions

The stream crossing is located along Pearl Street and Elmer Brook in South Hadley, Massachusetts, at approximate Latitude: 42°16'58" N; Longitude: 72°35'13" W. As part of a Municipal Vulnerability Preparedness (MVP) program grant, a town-wide road/stream crossing assessment identified this crossing as a top priority for replacement.

A field inspection for the existing culvert was completed by Fuss & O'Neill on September 9, 2022 and a topographic survey of Pearl Street was completed on September 22, 2022. The existing structure consists of one circular corrugated metal pipe culvert, measuring 6 feet in diameter and approximately 45 feet in length, projecting from the embankment.

### 2.2 Proposed Conditions

Pursuant to the Massachusetts Stream Crossing Standards, the replacement culvert should be a minimum of 1.2 times the bankfull width and have an optimal height of 6 feet.

Pearl Street is classified as an urban local road; MassDOT Chapter 85 guidelines therefore require that the design flood frequency be based on the 10-year storm, with the design scour frequency based on the 25-year storm, and the check scour frequency based on the 50-year storm. The RMAT guidelines are more stringent in this case. Based on level of criticality and an expected useful life of more than 50 years, it was determined that this culvert should be sized based on the Tier 2 RMAT rainfall recommendations. The 50-year storm was used for the design storm plus a 20% magnification for additional capacity to accommodate predicted climatic condition peak flows. The culvert height was selected based on the optimum openness ratio and optimum height requirements. Based on these requirements, the replacement structure is proposed to be a 16-foot span x 6-foot rise three-sided frame with an open bottom. The downstream scour pool within the brook will be improved through the implementation of root wads in the scour hole and streambanks.

## 3 Hydrologic Analysis

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A hydrologic model for Elmer Brook was developed using GeoHEC-HMS 1.2 software. The Soil Conservation Service (SCS) Curve Number (CN) methodology was used to represent the hydrologic losses for the watershed. The Snyder Unit Hydrograph method was used to simulate the excess rainfall-runoff response of the watershed. Details of the development of the hydrologic model are presented in the following sections.

### 3.1 Watershed Delineation

The Elmer Brook watershed was delineated using a 3-foot LiDAR based Digital Elevation Model (DEM) downloaded from NOAA Coastal Data Viewer (2015 USGS Lidar: Maine & Massachusetts QL1

& QL2). The outlet point was selected at the stream crossing of Pearl Street at Elmer Brook. The total watershed has an area of 3.7 sq mi.

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## 3.2 Curve Number Development

To determine the Curve Numbers (CN) for the watershed, soil and land use data were considered. The soil data were obtained from the USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) data, and the NCLD Land Cover Land Use data (2016) were obtained from Multi-Resolution Land Characteristics (MRLC) Consortium. The Land Cover Land Use data were then updated in GeoHEC-HMS based on field observations and aerial imagery, and the composite curve number was calculated in GeoHEC-HMS.

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## 3.3 Snyder Methodology

The GeoHEC-HMS model uses two parameters to define the runoff characteristics of a watershed when using the Snyder Unit Hydrograph methodology: Standard Lag ( $T_L$ ) and the Peaking Coefficient ( $C_P$ ).

The Standard Lag Time ( $T_L$ ) was computed using the Snyder watershed lag equation:

$$T_L = C_T(L \times L_{ca})^{0.3}$$

Where:

$C_T$  = Coefficient representing variations in watershed topography

$L$  = Longest Flow Path along main stream to basin divide (mi)

$L_{ca}$  = Centroidal Flow Path Length along main stream to watershed centroid (mi)

Based on guidance from the HEC-HMS technical manual, which presents typical ranges for  $C_T$  to be from 1.8 to 2.2, a value of 2.2 was used to calibrate the model based on the surrounding topography. The  $C_P$  value, which generally ranges from 0.4 to 0.8, was determined to be 0.4 via calibration as well. The longest flow path (4.9 miles) and centroidal flow path (2.8 miles) were then calculated for the watershed in GeoHEC-HMS.

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## 3.4 Design Storms

Unit hydrographs for the 2-, 5-, 10-, 25-, 50-, and 100-year storm events were determined using GeoHEC-HMS. The meteorological model in GeoHEC-HMS was set up for a hypothetical storm using an SCS Type 3 distribution. Precipitation depth values were obtained from NOAA Atlas 14 for the 24-hour storm events and are shown in Table 1. Both present and future climactic conditions were considered in this analysis. The crossing was classified as Tier 2 based on the RMAT Climate Resilience Design Standards Tool, included in Appendix B. Per Tier 2 RMAT methodology, present baseline precipitation depths from NOAA Atlas 14 were scaled by 27% for the 100-year design storm and 20% for more frequent design storms.

**Table 1: NOAA Atlas 14 Precipitation Depths for Present and Late Century**

Design Storm	Present Baseline Precipitation Depth (in)	Late Century (2070/2090) Precipitation Depth (in)
2-year	3.07	3.68
5-year	4.1	4.92
10-year	4.95	5.94
25-year	6.12	7.34
50-year	6.98	8.38
100-year	7.93	10.07

The peak flows were inputted into the HEC-RAS hydraulic model. Appendix B contains supporting documentation used to develop the HEC-HMS model. Appendix A contains the summary of the HEC-HMS model.

## 4 Hydraulic Analysis

To analyze the stream crossing of Elmer Brook at Pearl Street, a 1-dimensional (1D) HEC-RAS (version 6.1) hydraulic model was developed. The terrain was created from the LiDAR based Digital Elevation Model (DEM), downloaded from NOAA Coastal Data Viewer. Manning's n values were assigned using the NCLD Land Cover Land Use dataset and were assigned typical values from the HEC-RAS technical manual. The channel and road were updated with survey data collected in September 2022, as well as bathymetry data collected by Fuss and O'Neill staff in September 2022 using a GPS unit with sub-centimeter horizontal and vertical accuracy. The bathymetry data included ten channel and wetland cross sections and longitudinal profile data. The model terminates approximately 550 feet downstream from Pearl Street.

Under existing conditions, the roadway overtops in the 25-, 50-, and 100-year events. For future conditions, the culvert will be resized to prevent roadway overtopping during the future projected storm events.

### 4.1 Existing Conditions

The existing culvert is undersized, becoming submerged during a 10-year storm event, and overtopping the road during a 25-year storm event. The crossing is located within the FEMA floodplain, mapped as Zone A13 associated with backwater from the Connecticut River, however Elmer Brook has not been studied.

Table 2 below shows that the road (with an elevation of 127.41 feet) is overtopped during the 25-, 50-, and 100-year storms, based on the HEC-RAS analysis.

**Table 2: Existing Pearl Street WSEL**

Design Storm	Existing Conditions WSEL
2-year	121.47
5-year	123.2
10-year	124.68
25-year	127.69
50-year	128.05
100-year	128.18

## 4.2 Proposed Conditions

The proposed culvert was sized based on Massachusetts Stream Crossing Standards and the RMAT rainfall recommendations for a Tier 2 category. The RMAT guidance tool was used to determine categorization and the summary is included in Appendix B. The 50-year storm event with a 20% magnification factor for predicted future 2070 climatic conditions was used. Bankfull measurements at representative locations surrounding the crossing were averaged to be approximately 13 feet. The culvert height was selected based on the optimum openness ratio and optimum height requirements. The proposed culvert at the current crossing will be a 16 foot span x 6 foot rise three sided frame with open bottom. The openness ratio calculations for the culvert can be found in Appendix D.

Pearl Street is classified as an urban local road; Chapter 85 therefore requires the design flood frequency be based on the 10-year storm, a less stringent guideline than the design requirements determined by RMAT. Per the requirements of Chapter 85, the proposed design provides more than the required 2 feet of freeboard above the future projected 10-year WSEL to the low chord of the culvert. Table 3 compares the WSEL along Pearl Street for existing conditions, proposed conditions (2022) and future proposed conditions (2070). The table demonstrates that the proposed culvert will maintain or lower WSEL along Pearl Street in both the current climate, as well as 2070 projected climate conditions. The proposed conditions also will not overtop the road on a 100-year storm.

**Table 3: Pearl Street WSEL Comparison**

Design Storm	Existing Conditions WSEL	Proposed Conditions WSEL (2022)	Proposed Conditions WSEL (2070)
2-year	121.30	119.84	120.53
5-year	122.85	120.98	121.67
10-year	124.60	121.69	122.2
50-year	128.05	122.58	123.12
100-year	128.24	122.94	123.98

A summary report of the HEC-RAS hydraulic model is included in Appendix C.

## 5 Scour Safety/Stability Analyses

Four soil borings were taken within the wetland limits of the project. The sample within the channel near the stream crossing was identified as a brown silty sand. Particle grain size analyses were performed

on the streambed material upstream and downstream of the existing structure to determine the streambed  $D_{50}$  particle size in preparation for the development of the scour calculations. The  $D_{50}$  particle size was 0.1120. The results are included in Appendix E.

A scour safety assessment was performed in accordance with Section 1.3.3.5 of the MassDOT Bridge Manual utilizing values obtained from the HEC-RAS Model. The NCHRP 24-20 Abutment Scour Approach in HEC-18 was used to calculate the total abutment scour depth. It utilizes the ratio between the projected length of the embankment divided by the width of the floodplain to determine whether the structure experiences clear-water or live-bed scour. As the projected length of the embankment was greater than 75% of the width of the floodplain, live-bed scour was used.

Per MassDOT standards, the design frequency used to estimate total abutment scour is the 25-year storm event, and the check scour frequency is the 50-year storm event. A summary of calculated abutment scour depths are found in Table 4, and the calculation are found in Appendix E.

**Table 4: Summary of Calculated Scour**

Return Frequency (Year)	Design Abutment Scour Depth (ft)
25	3.8
50	5.5

The proposed culvert shall be supported on shallow foundations (spread footings) bearing on a crushed stone layer over natural soils.

## Appendix A

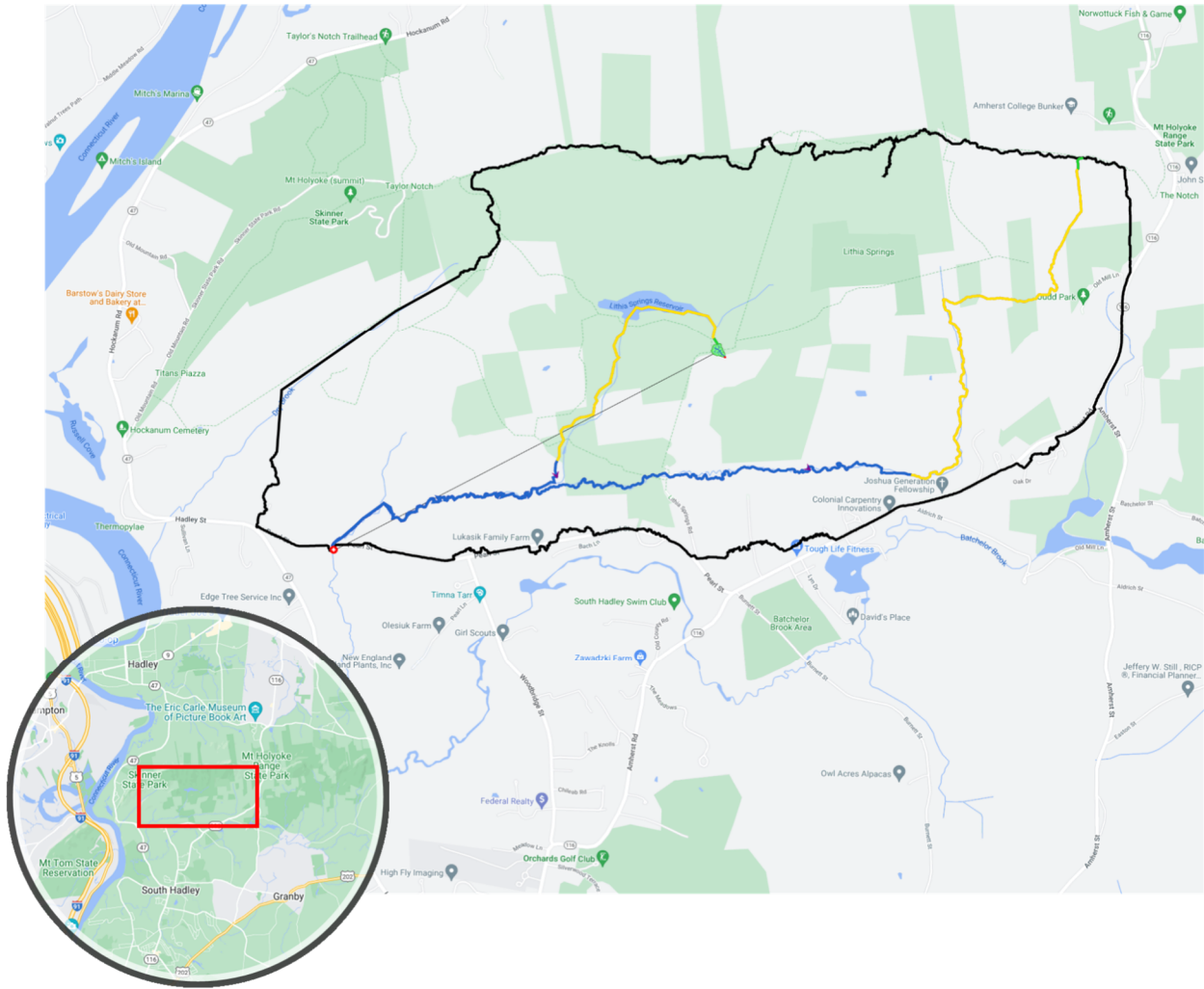
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### GeoHEC-HMS Hydrologic Model Summary Report



# Project Description

The project is located at **Lithia Springs Trail, South Hadley, MA 01075**. The site is 2,407.632 acres in size.



## Purpose

The purpose of this hydrology study is to determine the peak runoff rates for pre-development conditions.

## Methodology Used

The HEC-HMS version 4.5 computer software was used in this hydrology study. The **SCS Curve Number** infiltration (loss) method and **Snyder Unit Hydrograph** runoff (transform) method was used for determining the stormwater runoff. The **Kinematic Wave** routing method was used for routing the stormwater.

The following scenarios were analyzed in this hydrology study:

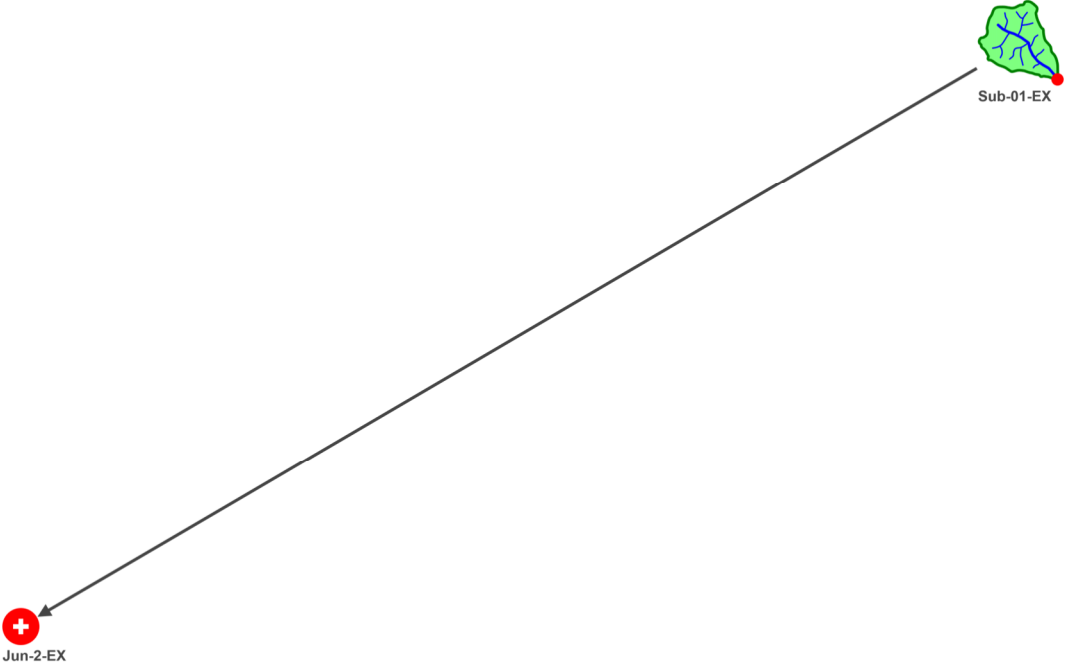
### SnyderSpreadsheet

This scenario contains:

- 1 delineated subbasin area and corresponding lag time flow paths
- 1 connecting junction

# SnyderSpreadsheet

## Watershed Routing Diagram



## Current Design Storms

### **2 Year Storm:**

Precipitation type: SCS Storm  
SCS storm distribution: Type III  
Rainfall depth: 3.07 in

### **5 Year Storm:**

Precipitation type: SCS Storm  
SCS storm distribution: Type III  
Rainfall depth: 4.1 in

### **10 Year Storm:**

Precipitation type: SCS Storm  
SCS storm distribution: Type III  
Rainfall depth: 4.95 in

### **25 Year Storm:**

Precipitation type: SCS Storm  
SCS storm distribution: Type III  
Rainfall depth: 6.12 in

### **50 Year Storm:**

Precipitation type: SCS Storm  
SCS storm distribution: Type III  
Rainfall depth: 6.98 in

### **100 Year Storm:**

Precipitation type: SCS Storm  
SCS storm distribution: Type III  
Rainfall depth: 7.93 in

## 2070 Design Storms

### **2 Year Storm:**

Precipitation type: SCS Storm  
SCS storm distribution: Type III  
Rainfall depth: 3.68 in

### **5 Year Storm:**

Precipitation type: SCS Storm  
SCS storm distribution: Type III  
Rainfall depth: 4.92 in

### **10 Year Storm:**

Precipitation type: SCS Storm

SCS storm distribution: Type III  
Rainfall depth: 5.94 in

**25 Year Storm:**

Precipitation type: SCS Storm  
SCS storm distribution: Type III  
Rainfall depth: 7.34 in

**50 Year Storm:**

Precipitation type: SCS Storm  
SCS storm distribution: Type III  
Rainfall depth: 8.38 in

**100 Year Storm:**

Precipitation type: SCS Storm  
SCS storm distribution: Type III  
Rainfall depth: 10.07 in

## Watershed Summary

Subbasin ID	Drainage Area (acres)	Initial Abstract (in)	Curve Number	Imperv Surface (%)	Peaking Coeff	Lag Time (minutes)
Sub-01-EX	2,406.919	1.35	59.72	1.01	0.4	230.51

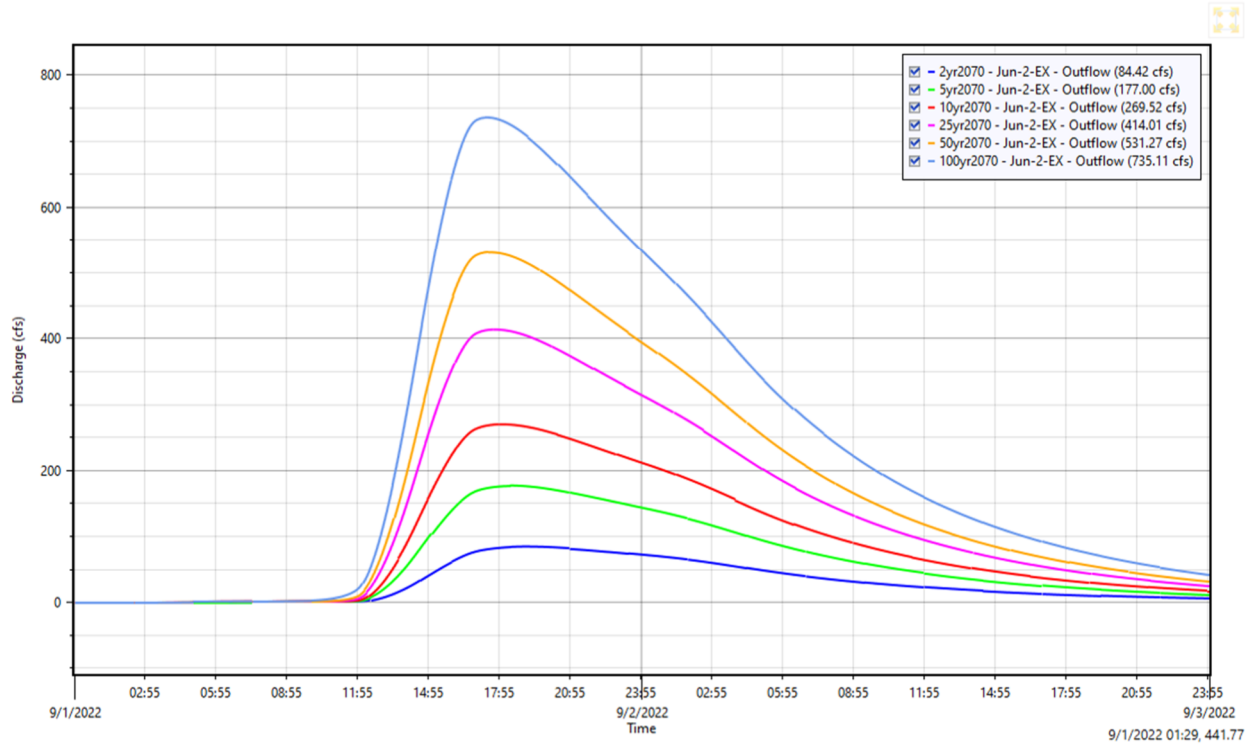
## Subbasins

<b>Subbasin ID:</b>	<b>Sub-01-EX</b>				
<b>Scenario:</b>	<b>SnyderSpreadsheet</b>				
<b>Drainage area:</b>	2,406.919 acres				
<b>Initial abstraction:</b>	1.35 in				
<b>Curve Number:</b>	59.72				
<b>Impervious surface:</b>	1.01%				
<b>Peaking coefficient:</b>	0.40				
<b>Lag time:</b>	290.35 minutes				
<b>Weighted Curve Number Calculations</b>					
<b>Soil Group</b>	<b>Land Use Description</b>	<b>Area (acres)</b>	<b>Area (%)</b>	<b>Composite CN</b>	
Undefined	Undeveloped, Grassland	2.197	0.09	43.93	
Undefined	Agricultural, Cultivated Crops	3.139	0.13	67.00	
Undefined	Developed, Medium Density	7.244	0.30	79.80	
Undefined	Woods1	235.560	9.78	55.08	
Undefined	Undeveloped, Evergreen Forest	186.214	7.73	47.45	
Undefined	Undeveloped, Barren Land	0.690	0.03	83.99	
Undefined	Wetlands, Forested	2.362	0.10	100.00	
Undefined	Undeveloped, Deciduous Forest	526.920	21.89	67.69	
Undefined	Developed, Low Density	22.273	0.93	66.28	
Undefined	Developed, Open Space	4.775	0.20	52.96	
Undefined	Wetlands, Non-Forested	0.230	0.01	100.00	
Undefined	Undefined Land	0.337	0.01	80.00	
Undefined	Undeveloped, Shrub/Scrub	606.393	25.19	62.03	
Undefined	Open Water	13.429	0.56	100.00	
Undefined	Agricultural, Pasture/Hay	42.158	1.75	40.93	
Undefined	Undeveloped, Mixed Forest	753.711	31.31	56.60	
<b>Weighted Average</b>		<b>2,407.632</b>	<b>100.00</b>	<b>59.72</b>	
<b>Time of Concentration (TOC) / Lag time Calculations</b>					
<b>Snyder Lag Time Calculations</b>					
L (miles)	Lc (miles)	Lag Time (hours)	Lag Time (min)		
4.898774621	2.825335227	4.8	290.3495547		
$t_l = C_t(L * L_c)^{0.3}$					
Ct = 2.2 basin coefficient					
L longest flow path					
Lc distance from outlet to near centroid along river					



# 2070 Flow

Element ID	Element Type	2 Year Peak Outflow (cfs)	5 Year Peak Outflow (cfs)	10 Year Peak Outflow (cfs)	25 Year Peak Outflow (cfs)	50 Year Peak Outflow (cfs)	100 Year Peak Outflow (cfs)
Jun-2-EX	Junction	84.42	177.00	269.52	414.01	531.27	735.11





## Appendix B

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### Supporting Information for Hydrologic Model Development

# Climate Resilience Design Standards Tool Project Report

## PearlStDER

Date Created: 11/7/2022 2:49:48 PM

Created By: sfrisby@fando.com

Date Report Generated: 11/7/2022 3:32:52 PM

Tool Version: Version 1.2

Project Contact Information: Sarah Frisby ([sfrisby@fando.com](mailto:sfrisby@fando.com))

## Project Summary

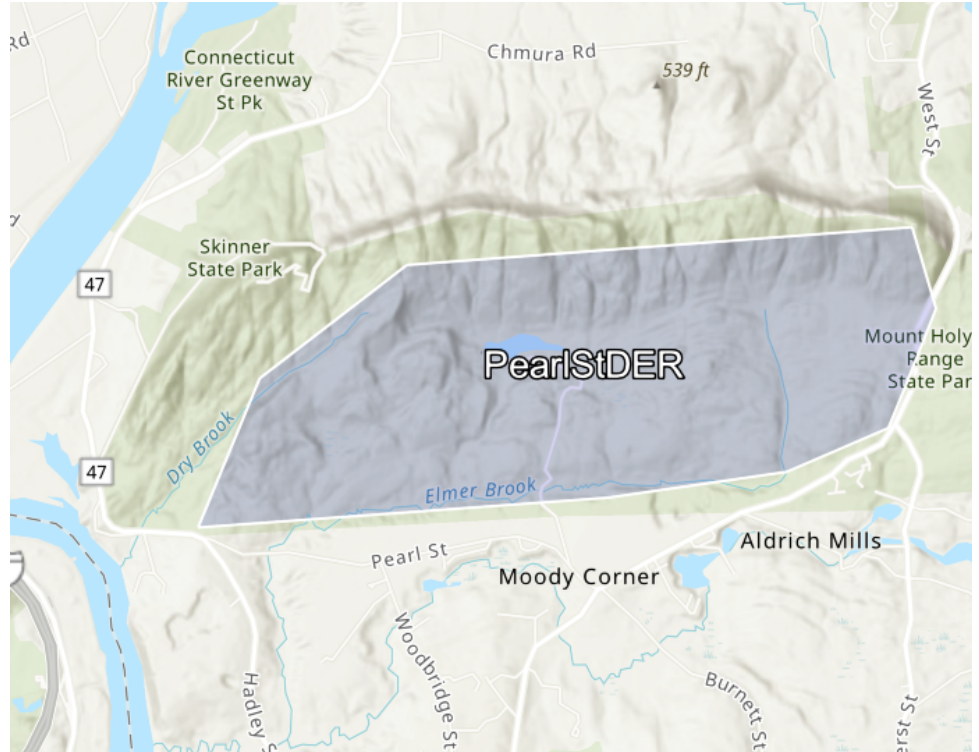
[Link to Project](#)

Estimated Capital Cost: \$147500.00

End of Useful Life Year: 2125

Project within mapped Environmental Justice neighborhood: No

Ecosystem Service	Scores
<b>Benefits</b>	
Project Score	Moderate
<b>Exposure</b>	
Sea Level Rise/Storm Surge	Not Exposed
Extreme Precipitation - Urban Flooding	High Exposure
Extreme Precipitation - Riverine Flooding	High Exposure
Extreme Heat	Moderate Exposure



## Asset Preliminary Climate Risk Rating

Number of Assets: 1

### Summary

Asset Risk	Sea Level Rise/Storm Surge	Extreme Precipitation - Urban Flooding	Extreme Precipitation - Riverine Flooding	Extreme Heat
Culvert	Low Risk	High Risk	High Risk	Moderate Risk

## Climate Resilience Design Standards Summary

	Target Planning Horizon	Intermediate Planning Horizon	Percentile	Return Period	Tier
<b>Sea Level Rise/Storm Surge</b>					
Culvert					
<b>Extreme Precipitation</b>					
Culvert	2070				Tier 2
<b>Extreme Heat</b>					
Culvert	2070		50th		Tier 2

## Scoring Rationale - Project Exposure Score

The purpose of the Exposure Score output is to provide a preliminary assessment of whether the overall project site and subsequent assets are exposed to impacts of natural hazard events and/or future impacts of climate change. For each climate parameter, the Tool will calculate one of the following exposure ratings: Not Exposed, Low Exposure, Moderate Exposure, or High Exposure. The rationale behind the exposure rating is provided below.

## Sea Level Rise/Storm Surge

This project received a "Not Exposed" because of the following:

- Not located within the predicted mean high water shoreline by 2030
- No historic coastal flooding at project site
- Not located within the Massachusetts Coast Flood Risk Model (MC-FRM)

## Extreme Precipitation - Urban Flooding

This project received a "High Exposure" because of the following:

- Historic flooding at the project site
- Maximum annual daily rainfall exceeds 10 inches within the overall project's useful life
- No increase to impervious area
- Existing impervious area of the project site is less than 10%

## Extreme Precipitation - Riverine Flooding

This project received a "High Exposure" because of the following:

- Project site has a history of riverine flooding
- Part of the project is within a mapped FEMA floodplain, outside of the Massachusetts Coast Flood Risk Model (MC-FRM)
- Part of the project is within 100ft of a waterbody
- Project is potentially susceptible to riverine erosion

## Extreme Heat

This project received a "Moderate Exposure" because of the following:

- 30+ days increase in days over 90 deg. F within project's useful life
- Existing impervious area of the project site is less than 10%
- Located within 100 ft of existing water body
- No increase to the impervious area of the project site
- No tree removal

## Scoring Rationale - Asset Preliminary Climate Risk Rating

A Preliminary Climate Risk Rating is determined for each infrastructure and building asset by considering the overall project Exposure Score and responses to Step 4 questions provided by the user in the Tool. Natural Resource assets do not receive a risk rating. The following factors are what influenced the risk ratings for each asset.

### Asset - Culvert

Primary asset criticality factors influencing risk ratings for this asset:

- Asset can be inaccessible/inoperable more than a week after natural hazard event without consequences
- Loss/inoperability of the asset would have impacts limited to local area and/or municipality
- Inoperability of the asset would not be expected to result in injuries
- Inoperability may moderately impact other facilities, assets, or buildings, but is not expected to affect their ability to operate
- Impact on natural resources can be mitigated naturally with the inoperability of the asset

## Project Climate Resilience Design Standards Output

Climate Resilience Design Standards and Guidance are recommended for each asset and climate parameter. The Design Standards for each climate parameter include the following: recommended planning horizon (target and/or intermediate), recommended return period (Sea Level Rise/Storm Surge and Precipitation) or percentile (Heat), and a list of applicable design criteria that are likely to be affected by climate change. Some design criteria have numerical values associated with the recommended return period and planning horizon, while others have tiered methodologies with step-by-step instructions on how to estimate design values given the other recommended design standards.

Asset: Culvert

Infrastructure

### Sea Level Rise/Storm Surge

Low Risk

#### Applicable Design Criteria

**Projected Tidal Datums:** NOT APPLICABLE

**Projected Water Surface Elevation:** NOT APPLICABLE

**Projected Wave Action Water Elevation:** NOT APPLICABLE

**Projected Wave Heights:** NOT APPLICABLE

**Projected Duration of Flooding:** NOT APPLICABLE

**Projected Design Flood Velocity:** NOT APPLICABLE

**Projected Scour & Erosion:** NOT APPLICABLE

### Extreme Precipitation

High Risk

Target Planning Horizon: 2070

Return Period: No Return Period

**LIMITATIONS:** The recommended Standards for Total Precipitation Depth & Peak Intensity are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The projected Total Precipitation Depth values provided through the Tool are based on the climate projections developed by Cornell University as part of EEA's Massachusetts Climate and Hydrologic Risk Project, GIS-based data as of 10/15/21. For additional information on the methodology of these precipitation outputs, see Supporting Documents.

While Total Precipitation Depth & Peak Intensity for 24-hour Design Storms are useful to inform planning and design, it is recommended to also consider additional longer- and shorter-duration precipitation events and intensities in accordance with best practices. Longer-duration, lower-intensity storms allow time for infiltration and reduce the load on infrastructure over the duration of the storm. Shorter-duration, higher-intensity storms often have higher runoff volumes because the water does not have enough time to infiltrate infrastructure systems (e.g., catch basins) and may overflow or back up during such storms, resulting in flooding. In the Northeast, short-duration high intensity rain events are becoming more frequent, and there is often little early warning for these events, making it difficult to plan operationally. While the Tool does not provide recommended design standards for these scenarios, users should still consider both short- and long-duration precipitation events and how they may impact the asset.

The projected values, standards, and guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence

#### Applicable Design Criteria

**Tiered Methodology:** Tier 2

**Projected Total Precipitation Depth & Peak Intensity for 24-hr Design Storms:** APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period (Design Storm)	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Methodology for Peak Intensity
Culvert	2070	No Return Period	N/A	<a href="#">Downloadable Methodology. PDE</a>

**Projected Riverine Peak Discharge & Peak Flood Elevation:** NOT APPLICABLE

### Extreme Heat

Moderate Risk

Target Planning Horizon: 2070  
Percentile: 50th Percentile

**Applicable Design Criteria**

**Tiered Methodology:** Tier 2

**Projected Annual/Summer/Winter Average Temperatures:** APPLICABLE  
[Methodology to Estimate Projected Values](#) : Tier 2

**Projected Heat Index:** APPLICABLE  
[Methodology to Estimate Projected Values](#) : Tier 2

**Projected Growing Degree Days:** NOT APPLICABLE

**Projected Days Per Year With Max Temp > 95°F, >90°F, <32°F:** APPLICABLE  
[Methodology to Estimate Projected Values](#) : Tier 2

**Projected Number of Heat Waves Per Year & Average Heat Wave Duration:** APPLICABLE  
[Methodology to Estimate Projected Values](#) : Tier 2

**Projected Cooling Degree Days & Heating Degree Days (base = 65°F):** NOT APPLICABLE

## Project Inputs

### Core Project Information

Name:	PearlStDER
Given the expected useful life of the project, through what year do you estimate the project to last (i.e. before a major reconstruction/renovation)?	2125
Location of Project:	Granby, S. Hadley
Estimated Capital Cost:	\$147,500
Who is the Submitting Entity?	Private Other Fuss & O'Neill Sarah Frisby (sfrisby@fando.com)
Is this project being submitted as part of a state grant application?	No
Which grant program?	
What stage are you in your project lifecycle?	Design
Is climate resiliency a core objective of this project?	Yes
Is this project being submitted as part of the state capital planning process?	No
Is this project being submitted as part of a regulatory review process or permitting?	Yes
Brief Project Description:	Culvert replacement to RMA stream crossing standards
Project Submission Comments:	

### Project Ecosystem Service Benefits

#### Factors Influencing Output

- ✓ Project provides flood protection through nature-based solutions
- ✓ Project reduces storm damage
- ✓ Project improves water quality
- ✓ Project protects fisheries, wildlife, and plant habitat

#### Factors to Improve Output

- ✓ Protect public water supply by reducing the risk of contamination, pollution, and/or runoff of surface and groundwater sources used for human consumption
- ✓ Incorporate green infrastructure or nature-based solutions that recharge groundwater
- ✓ Incorporate green infrastructure to filter stormwater
- ✓ Identify opportunities to prevent pollutants from impacting ecosystems

#### Is the primary purpose of this project ecological restoration?

No

### Project Benefits

Provides flood protection through nature-based solutions	Yes
Reduces storm damage	Yes
Recharges groundwater	Maybe
Protects public water supply	Maybe
Filters stormwater using green infrastructure	Maybe
Improves water quality	Yes
Promotes decarbonization	No
Enables carbon sequestration	No
Provides oxygen production	No
Improves air quality	No
Prevents pollution	Maybe
Remediates existing sources of pollution	No
Protects fisheries, wildlife, and plant habitat	Yes
Protects land containing shellfish	No
Provides pollinator habitat	No
Provides recreation	No
Provides cultural resources/education	No

### Project Climate Exposure

Is the primary purpose of this project ecological restoration?	No
Does the project site have a history of coastal flooding?	No
Does the project site have a history of flooding during extreme precipitation events (unrelated to water/sewer damages)?	Yes
Does the project site have a history of riverine flooding?	Yes
Does the project result in a net increase in impervious area of the site?	No
Are existing trees being removed as part of the proposed project?	No

### Project Assets

Asset: Culvert  
Asset Type: Other  
Asset Sub-Type: Other

Construction Type: New Construction

Construction Year: 2025

Useful Life: 100

**Identify the length of time the asset can be inaccessible/inoperable without significant consequences.**

Infrastructure may be inaccessible/inoperable more than a week after natural hazard event without consequences.

**Identify the geographic area directly affected by permanent loss or significant inoperability of the infrastructure.**

Impacts would be limited to local area and/or municipality

**Identify the population directly served that would be affected by the permanent loss or significant inoperability of the infrastructure.**

Less than 5,000 people

**Identify if the infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.**

The infrastructure does not provide services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.

**Will the infrastructure reduce the risk of flooding?**

Yes

**If the infrastructure became inoperable for longer than acceptable in Question 1, how, if at all, would it be expected to impact people's health and safety?**

Inoperability of the infrastructure would not be expected to result in injuries

**If there are hazardous materials in your infrastructure, what are the extents of impacts related to spills/releases of these materials?**

There are no hazardous materials in the infrastructure

**If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts on other facilities, assets, and/or infrastructure?**

Moderate – Inoperability may impact other facilities, assets, or buildings, but cascading impacts do not affect the ability of other facilities, assets, or buildings to operate

**If the infrastructure was damaged beyond repair, how much would it approximately cost to replace?**

Less than \$10 million

**Does the infrastructure function as an evacuation route during emergencies? This question only applies to roadway projects.**

No

**If the infrastructure became inoperable for longer than acceptable in Question 1, what are the environmental impacts related to natural resources?**

Impact on natural resources can be mitigated naturally

**If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts to government services (i.e. the infrastructure is not able to serve or operate its intended users or function)?**

Loss of infrastructure is not expected to reduce the ability to maintain government services

**What are the impacts to loss of confidence in government resulting from loss of infrastructure functionality (i.e. the infrastructure asset is not able to serve or operate its intended users or function)?**

Reduced morale and public support

## Report Comments

N/A

## Appendix C

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### HEC-RAS Hydraulic Model Summary Report



Existing Conditions Hydraulic Results												
Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
Reach 1	1023	2yr	49.28	119.41	122.13	120.81	122.16	0.001016	1.4	35.31	21.75	0.19
Reach 1	1023	5yr	112.9	119.41	123.45	121.32	123.49	0.000728	1.62	80.23	89.04	0.18
Reach 1	1023	10yr	179.53	119.41	124.74	121.73	124.75	0.000179	1.05	274.62	188.18	0.09
Reach 1	1023	25yr	287.07	119.41	127.6	122.27	127.61	0.000018	0.48	876.69	225.17	0.03
Reach 1	1023	50yr	375.23	119.41	128.07	122.64	128.07	0.000021	0.55	981.62	228.17	0.04
Reach 1	1023	100yr	479.65	119.41	128.26	123.08	128.26	0.000031	0.67	1025.25	229.5	0.04
Reach 1	916	2yr	49.28	118.49	121.87		121.96	0.004008	2.48	19.84	12.62	0.35
Reach 1	916	5yr	112.9	118.49	123.33		123.38	0.001547	1.9	71.79	68.9	0.24
Reach 1	916	10yr	179.53	118.49	124.71		124.73	0.00028	1.15	240.12	191.97	0.11
Reach 1	916	25yr	287.07	118.49	127.6		127.6	0.00002	0.46	890.33	248.95	0.03
Reach 1	916	50yr	375.23	118.49	128.06		128.07	0.000023	0.53	1006.53	253.61	0.04
Reach 1	916	100yr	479.65	118.49	128.25		128.26	0.000033	0.64	1054.77	255.03	0.04
Reach 1	795	2yr	49.28	118.29	121.6		121.65	0.001669	1.75	28.11	16.91	0.24
Reach 1	795	5yr	112.9	118.29	123.25		123.28	0.000493	1.48	115.64	113.45	0.15
Reach 1	795	10yr	179.53	118.29	124.7		124.7	0.000125	0.96	317.44	198.91	0.08
Reach 1	795	25yr	287.07	118.29	127.6		127.6	0.000014	0.45	1019.95	277.54	0.03
Reach 1	795	50yr	375.23	118.29	128.06		128.06	0.000017	0.51	1151.77	290.7	0.03
Reach 1	795	100yr	479.65	118.29	128.25		128.25	0.000025	0.62	1206.93	293.63	0.04
Reach 1	682	2yr	49.28	118.76	121.52		121.54	0.000531	1.15	42.73	21.02	0.14
Reach 1	682	5yr	112.9	118.76	123.22		123.24	0.000222	1.11	152.48	140.09	0.1
Reach 1	682	10yr	179.53	118.76	124.69		124.69	0.000068	0.77	391	193.56	0.06
Reach 1	682	25yr	287.07	118.76	127.6		127.6	0.00001	0.4	1147.89	291.71	0.02
Reach 1	682	50yr	375.23	118.76	128.06		128.06	0.000013	0.46	1285.28	301.35	0.03
Reach 1	682	100yr	479.65	118.76	128.25		128.25	0.000018	0.56	1342.19	303.73	0.03
Reach 1	644	2yr	49.28	118.3	121.49		121.52	0.000809	1.42	34.77	16.57	0.17
Reach 1	644	5yr	112.9	118.3	123.2		123.23	0.000401	1.46	115.03	121.98	0.13
Reach 1	644	10yr	179.53	118.3	124.68		124.69	0.000096	0.89	342.66	181.8	0.07
Reach 1	644	25yr	287.07	118.3	127.6		127.6	0.000013	0.44	1065.57	289.26	0.03
Reach 1	644	50yr	375.23	118.3	128.06		128.06	0.000016	0.51	1200.78	297.18	0.03
Reach 1	644	100yr	479.65	118.3	128.25		128.25	0.000023	0.62	1257.81	309.19	0.04
Reach 1	615	2yr	49.28	118.3	121.47		121.49	0.000612	1.15	42.98	24.35	0.15
Reach 1	615	5yr	112.9	118.3	123.2		123.21	0.000284	1.05	126.12	82.65	0.11
Reach 1	615	10yr	179.53	118.3	124.68		124.69	0.000104	0.85	285.99	138.56	0.07
Reach 1	615	25yr	287.07	118.3	127.6		127.6	0.00002	0.53	864.35	285.28	0.04
Reach 1	615	50yr	375.23	118.3	128.06		128.06	0.000024	0.6	999.11	297.66	0.04
Reach 1	615	100yr	479.65	118.3	128.25		128.25	0.000034	0.73	1055.3	303.54	0.05
Reach 1	608	2yr	49.28	118.28	121.48		121.49	0.000439	0.88	56.44	40.08	0.13
Reach 1	608	5yr	112.9	118.28	123.2		123.21	0.000158	0.89	139.85	71.65	0.09
Reach 1	608	10yr	179.53	118.28	124.68		124.69	0.000081	0.82	280.71	118.58	0.07
Reach 1	608	25yr	287.07	118.28	127.6		127.6	0.00002	0.56	785.46	237.5	0.04
Reach 1	608	50yr	375.23	118.28	128.06		128.06	0.000025	0.66	900.82	263.21	0.04
Reach 1	608	100yr	479.65	118.28	128.24		128.25	0.000036	0.8	950.42	269.23	0.05
Reach 1	602	2yr	49.28	118.5	121.3	120.05	121.47	0.002965	3.24	15.21	9.6	0.36
Reach 1	602	5yr	112.9	118.5	122.85	120.99	123.18	0.003196	4.62	24.45	12.46	0.4
Reach 1	602	10yr	179.53	118.5	124.6	121.8	124.68	0.000099	2.4	108.07	80.52	0.2
Reach 1	602	25yr	287.07	118.5	127.59	122.91	127.6	0.000081	0.96	518.06	201.3	0.06
Reach 1	602	50yr	375.23	118.5	128.05	123.72	128.06	0.00009	1.05	616.43	225.05	0.07
Reach 1	602	100yr	479.65	118.5	128.24	124.55	128.25	0.00013	1.28	659.12	237.98	0.08
Reach 1	578	Culvert										
Reach 1	551	2yr	49.28	118	119.91	119.91	120.55	0.030525	6.42	7.67	8.75	1
Reach 1	551	5yr	112.9	118	120.85	120.85	121.97	0.02545	8.47	13.33	11.03	1
Reach 1	551	10yr	179.53	118	121.66	121.66	123.18	0.022853	9.88	18.18	14.46	1
Reach 1	551	25yr	287.07	118	122.77	122.77	124.85	0.020645	11.56	24.84	30.99	1
Reach 1	551	50yr	375.23	118	123.59	123.59	126.06	0.019344	12.62	29.74	69.54	1
Reach 1	551	100yr	479.65	118	124.03	124.03	124.43	0.005315	5.67	132.43	125.37	0.49
Reach 1	541	2yr	49.28	117	119.65	117.95	119.66	0.000536	1.06	46.32	27.49	0.14
Reach 1	541	5yr	112.9	117	120.85	118.5	120.88	0.000577	1.31	85.91	39.24	0.16
Reach 1	541	10yr	179.53	117	121.57	118.92	121.61	0.000646	1.54	116.2	45.12	0.17

Existing Conditions Hydraulic Results

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
Reach 1	541	25yr	287.07	117	122.15	119.42	122.21	0.000902	2	143.62	50.16	0.21	
Reach 1	541	50yr	375.23	117	122.44	119.76	122.53	0.001125	2.38	158.46	51.92	0.23	
Reach 1	541	100yr	479.65	117	122.72	120.13	122.84	0.001384	2.79	173.49	53.55	0.26	
Reach 1	526	2yr	49.28	116	119.66		119.66	0.000067	0.46	106.72	46.24	0.05	
Reach 1	526	5yr	112.9	116	120.86		120.87	0.000096	0.67	167.94	54.18	0.07	
Reach 1	526	10yr	179.53	116	121.59		121.6	0.000132	0.86	208.99	59.22	0.08	
Reach 1	526	25yr	287.07	116	122.17		122.19	0.00021	1.18	244.11	61.63	0.1	
Reach 1	526	50yr	375.23	116	122.47		122.5	0.000282	1.43	262.78	62.88	0.12	
Reach 1	526	100yr	479.65	116	122.77		122.81	0.000368	1.71	286.57	108.34	0.14	
Reach 1	439	2yr	49.28	117.45	119.41		119.62	0.010508	3.7	13.33	10.83	0.59	
Reach 1	439	5yr	112.9	117.45	120.55		120.82	0.007242	4.16	27.14	13.71	0.51	
Reach 1	439	10yr	179.53	117.45	121.23		121.53	0.006985	4.59	45.67	45.19	0.51	
Reach 1	439	25yr	287.07	117.45	121.89		122.12	0.005291	4.45	100.63	118.09	0.45	
Reach 1	439	50yr	375.23	117.45	122.23		122.42	0.004407	4.36	144.07	138.69	0.42	
Reach 1	439	100yr	479.65	117.45	122.57		122.73	0.003561	4.17	193.25	151.74	0.38	
Reach 1	310	2yr	49.28	116.76	119.11		119.15	0.001529	1.68	29.38	18.23	0.23	
Reach 1	310	5yr	112.9	116.76	120.34		120.39	0.001468	1.92	58.73	29.4	0.24	
Reach 1	310	10yr	179.53	116.76	121.03		121.11	0.001492	2.22	81.39	36.72	0.25	
Reach 1	310	25yr	287.07	116.76	121.58		121.71	0.001889	2.86	104.32	47.91	0.29	
Reach 1	310	50yr	375.23	116.76	121.83		122.01	0.002427	3.42	117	55.75	0.34	
Reach 1	310	100yr	479.65	116.76	122.04		122.29	0.003122	4.05	130.47	89.5	0.38	
Reach 1	198	2yr	49.28	116.56	118.88		118.95	0.002267	1.99	24.7	14.68	0.27	
Reach 1	198	5yr	112.9	116.56	120.09		120.19	0.002313	2.51	44.97	19.04	0.29	
Reach 1	198	10yr	179.53	116.56	120.72		120.87	0.003018	3.1	58.77	33.9	0.34	
Reach 1	198	25yr	287.07	116.56	121.2		121.41	0.003733	3.84	99.04	137.17	0.39	
Reach 1	198	50yr	375.23	116.56	121.43		121.65	0.004059	4.2	133.43	163.52	0.41	
Reach 1	198	100yr	479.65	116.56	121.62		121.87	0.004489	4.59	167.38	186.92	0.43	
Reach 1	73	2yr	49.28	116.22	118.54	117.57	118.62	0.003005	2.29	21.53	14.11	0.33	
Reach 1	73	5yr	112.9	116.22	119.75	118.22	119.86	0.003005	2.67	43.07	36.08	0.34	
Reach 1	73	10yr	179.53	116.22	120.37	118.74	120.48	0.003005	2.82	75.44	72.26	0.35	
Reach 1	73	25yr	287.07	116.22	120.85	119.46	120.96	0.003	2.97	139.78	199.77	0.35	
Reach 1	73	50yr	375.23	116.22	121.08	120.17	121.18	0.003002	3.07	190.29	242.09	0.35	
Reach 1	73	100yr	479.65	116.22	121.27	120.69	121.37	0.003	3.22	238.33	261.31	0.36	

Proposed Conditions Hydraulic Results												
Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
Reach 1	1023	2yr	84.42	119.38	122.62	120.64	122.66	0.000834	1.57	53.61	23.92	0.19
Reach 1	1023	5yr	177	119.38	123.52	121.3	123.59	0.001158	2.23	93.28	93.08	0.23
Reach 1	1023	10yr	269.52	119.38	123.96	121.81	124.05	0.001295	2.59	148.25	144.54	0.25
Reach 1	1023	25yr	414.01	119.38	124.44	122.45	124.53	0.00132	2.85	228.2	174.34	0.26
Reach 1	1023	50yr	531.27	119.38	124.81	122.88	124.9	0.001208	2.9	295.29	189.42	0.25
Reach 1	1023	100yr	735.11	119.38	125.62	124.01	125.68	0.000757	2.58	452.75	201.19	0.2
Reach 1	916	2yr	84.42	118.49	122.28		122.45	0.00744	3.28	25.76	18	0.48
Reach 1	916	5yr	177	118.49	123.21		123.36	0.0051	3.29	63.81	60.61	0.43
Reach 1	916	10yr	269.52	118.49	123.65		123.81	0.004382	3.53	97.97	93.72	0.41
Reach 1	916	25yr	414.01	118.49	124.14		124.3	0.003845	3.76	151.15	117.5	0.4
Reach 1	916	50yr	531.27	118.49	124.53		124.69	0.003319	3.81	207.13	171.87	0.38
Reach 1	916	100yr	735.11	118.49	125.5		125.57	0.001288	2.84	400.75	210.94	0.25
Reach 1	795	2yr	84.42	118.29	121.49		121.65	0.005833	3.22	26.23	16.17	0.45
Reach 1	795	5yr	177	118.29	122.5		122.74	0.005027	3.95	47.27	34.13	0.45
Reach 1	795	10yr	269.52	118.29	123.15		123.33	0.003497	3.86	103.7	110.52	0.39
Reach 1	795	25yr	414.01	118.29	123.8		123.93	0.002363	3.6	181.5	125.72	0.33
Reach 1	795	50yr	531.27	118.29	124.27		124.38	0.001867	3.46	242.99	137.99	0.3
Reach 1	795	100yr	735.11	118.29	125.39		125.45	0.000799	2.65	462.73	222.22	0.2
Reach 1	682	2yr	84.42	118.76	121.07		121.16	0.003068	2.51	33.57	19.29	0.34
Reach 1	682	5yr	177	118.76	122.17		122.31	0.002593	3.05	64.19	49.27	0.33
Reach 1	682	10yr	269.52	118.76	122.88		123.02	0.002068	3.19	113.73	89.34	0.31
Reach 1	682	25yr	414.01	118.76	123.6		123.71	0.001576	3.17	207.53	150.46	0.28
Reach 1	682	50yr	531.27	118.76	124.12		124.21	0.001179	2.97	289.57	163.59	0.24
Reach 1	682	100yr	735.11	118.76	125.32		125.37	0.000573	2.41	531.76	245.92	0.18
Reach 1	644	2yr	84.42	118.3	120.78		120.98	0.007425	3.58	23.61	15.16	0.51
Reach 1	644	5yr	177	118.3	121.86		122.15	0.006293	4.31	41.18	19.03	0.49
Reach 1	644	10yr	269.52	118.3	122.46		122.86	0.006672	5.14	56.76	38.79	0.52
Reach 1	644	25yr	414.01	118.3	123.25		123.59	0.004872	5.14	121.89	124.06	0.47
Reach 1	644	50yr	531.27	118.3	123.97		124.14	0.00242	4.07	220.84	157.37	0.34
Reach 1	644	100yr	735.11	118.3	125.28		125.34	0.000761	2.7	456.88	199.82	0.2
Reach 1	615	2yr	84.42	118.3	120.61		120.78	0.006184	3.29	25.66	16.78	0.47
Reach 1	615	5yr	177	118.3	121.76		121.95	0.005397	3.52	50.34	27.29	0.46
Reach 1	615	10yr	269.52	118.3	122.41		122.64	0.005228	3.81	71.59	40.91	0.46
Reach 1	615	25yr	414.01	118.3	123.23		123.43	0.003653	3.78	128.53	83.6	0.4
Reach 1	615	50yr	531.27	118.3	123.91		124.07	0.002283	3.47	192.26	102.17	0.33
Reach 1	615	100yr	735.11	118.3	125.23		125.32	0.000948	2.78	368.94	160.51	0.23
Reach 1	608	2yr	84.42	118.28	120.5		120.71	0.014457	3.64	23.19	25.94	0.68
Reach 1	608	5yr	177	118.28	121.79		121.9	0.002909	2.58	69.31	40.78	0.34
Reach 1	608	10yr	269.52	118.28	122.46		122.59	0.002293	2.83	97.23	44.18	0.32
Reach 1	608	25yr	414.01	118.28	123.24		123.4	0.00201	3.2	143.07	72.98	0.31
Reach 1	608	50yr	531.27	118.28	123.9		124.05	0.001575	3.2	197.63	94.89	0.29
Reach 1	608	100yr	735.11	118.28	125.21		125.31	0.000835	2.83	349.92	141.25	0.22
Reach 1	602	2yr	84.42	118.27	120.54	119.37	120.65	0.002973	2.62	32.18	15.63	0.32
Reach 1	602	5yr	177	118.27	121.68	120.04	121.87	0.00306	3.53	50.22	15.94	0.35
Reach 1	602	10yr	269.52	118.27	122.22	120.58	122.55	0.004188	4.59	58.89	15.98	0.42
Reach 1	602	25yr	414.01	118.27	122.74	121.28	123.33	0.00639	6.18	67.17	15.99	0.53
Reach 1	602	50yr	531.27	118.27	123.16	121.78	123.97	0.007681	7.22	73.87	20.86	0.59
Reach 1	602	100yr	735.11	118.27	124.53	122.58	125.24	0.005192	7.05	136.25	78.12	0.51
Reach 1	576		Bridge									
Reach 1	551	2yr	84.42	118	120.41	119.07	120.5	0.002383	2.44	34.53	15.54	0.29

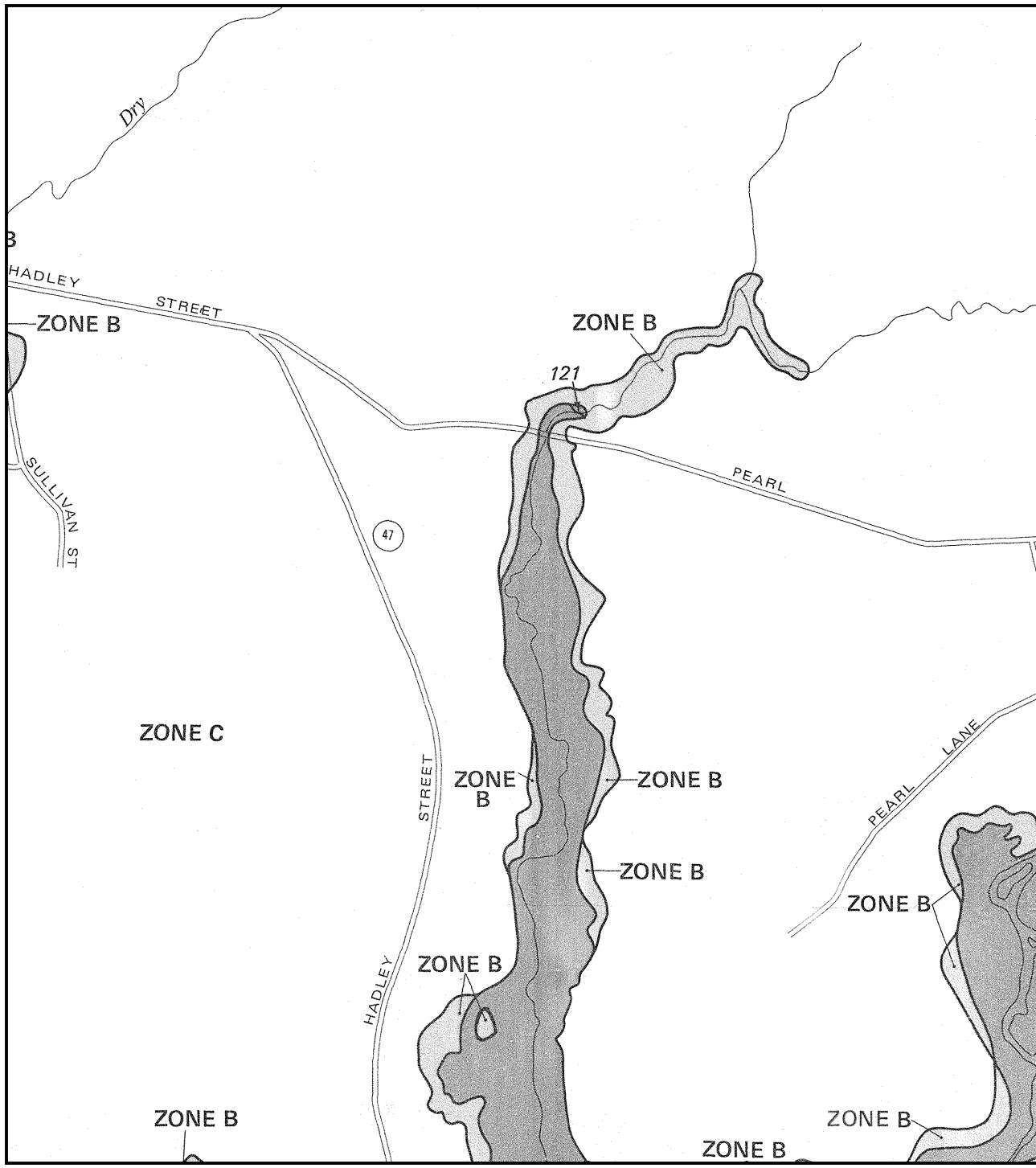
Proposed Conditions Hydraulic Results												
Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
Reach 1	551	5yr	177	118	121.54	119.74	121.72	0.002667	3.4	52.27	15.89	0.33
Reach 1	551	10yr	269.52	118	122.02	120.29	122.33	0.003963	4.53	59.87	15.98	0.41
Reach 1	551	25yr	414.01	118	122.35	121	122.99	0.007049	6.39	65.28	21.61	0.55
Reach 1	551	50yr	531.27	118	122.52	121.51	123.48	0.010195	7.89	67.91	24.89	0.67
Reach 1	551	100yr	735.11	118	122.54	122.32	124.37	0.019167	10.85	68.29	25.36	0.92
Reach 1	541	2yr	84.42	117.95	120.43		120.46	0.000903	1.41	59.81	34.57	0.19
Reach 1	541	5yr	177	117.95	121.59		121.63	0.000835	1.66	106.61	45.3	0.19
Reach 1	541	10yr	269.52	117.95	122.12		122.19	0.001044	2.04	132.05	50.02	0.22
Reach 1	541	25yr	414.01	117.95	122.59		122.7	0.001454	2.68	155.83	52.77	0.26
Reach 1	541	50yr	531.27	117.95	122.89		123.04	0.001762	3.13	172	54.49	0.3
Reach 1	541	100yr	735.11	117.95	123.29		123.51	0.002271	3.82	211.18	125.15	0.34
Reach 1	526	2yr	84.42	117.8	120.43		120.45	0.000318	0.93	91.09	45.46	0.12
Reach 1	526	5yr	177	117.8	121.6		121.62	0.000333	1.19	148.15	51.96	0.12
Reach 1	526	10yr	269.52	117.8	122.13		122.17	0.000455	1.53	176.94	56.79	0.15
Reach 1	526	25yr	414.01	117.8	122.6		122.67	0.000681	2.04	205.46	65.29	0.19
Reach 1	526	50yr	531.27	117.8	122.92		123	0.00084	2.39	237.85	120.39	0.21
Reach 1	526	100yr	735.11	117.8	123.34		123.46	0.001065	2.88	300.28	164.07	0.24
Reach 1	439	2yr	84.42	117.45	120.11		120.35	0.007816	3.92	21.52	12.32	0.52
Reach 1	439	5yr	177	117.45	121.21		121.51	0.006999	4.58	44.79	42.9	0.51
Reach 1	439	10yr	269.52	117.45	121.81		122.05	0.005623	4.51	91.33	110.07	0.46
Reach 1	439	25yr	414.01	117.45	122.36		122.54	0.004044	4.28	162.61	144.07	0.4
Reach 1	439	50yr	531.27	117.45	122.71		122.87	0.003346	4.15	216.1	160.56	0.37
Reach 1	439	100yr	735.11	117.45	123.18		123.32	0.002842	4.13	300.06	185.88	0.35
Reach 1	310	2yr	84.42	116.76	119.85		119.9	0.00159	1.86	45.36	25.16	0.24
Reach 1	310	5yr	177	116.76	121.01		121.09	0.00149	2.2	80.68	36.48	0.25
Reach 1	310	10yr	269.52	116.76	121.52		121.64	0.001793	2.75	101.37	46.32	0.28
Reach 1	310	25yr	414.01	116.76	121.91		122.12	0.002683	3.66	121.85	58.16	0.35
Reach 1	310	50yr	531.27	116.76	122.14		122.42	0.003437	4.32	140.48	118.6	0.4
Reach 1	310	100yr	735.11	116.76	122.44		122.83	0.004543	5.25	185.47	173.87	0.47
Reach 1	198	2yr	84.42	116.56	119.6		119.68	0.002345	2.34	36.11	17.2	0.28
Reach 1	198	5yr	177	116.56	120.7		120.85	0.002994	3.07	58.2	32.81	0.34
Reach 1	198	10yr	269.52	116.56	121.14		121.35	0.003647	3.75	91.75	127.5	0.38
Reach 1	198	25yr	414.01	116.56	121.5		121.74	0.004228	4.35	146.21	171.72	0.42
Reach 1	198	50yr	531.27	116.56	121.72		121.97	0.004489	4.67	186.44	195.37	0.43
Reach 1	198	100yr	735.11	116.56	122		122.27	0.004899	5.13	243.71	214.87	0.46
Reach 1	73	2yr	84.42	116.22	119.25	117.96	119.35	0.003002	2.61	32.41	17.33	0.34
Reach 1	73	5yr	177	116.22	120.35	118.71	120.46	0.003005	2.81	74.2	70.76	0.34
Reach 1	73	10yr	269.52	116.22	120.8	119.37	120.91	0.003001	2.95	129.24	179.63	0.35
Reach 1	73	25yr	414.01	116.22	121.15	120.3	121.26	0.003002	3.13	208.64	250.68	0.35
Reach 1	73	50yr	531.27	116.22	121.36	120.79	121.47	0.003004	3.3	263.9	268.37	0.36
Reach 1	73	100yr	735.11	116.22	121.63	121.08	121.75	0.003002	3.52	338.46	279.72	0.36

## Appendix D

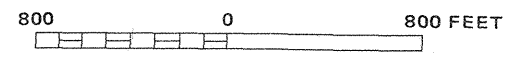
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### Supporting Information for Hydraulic Model Development





APPROXIMATE SCALE



NATIONAL FLOOD INSURANCE PROGRAM

**FIRM**  
FLOOD INSURANCE RATE MAP

TOWN OF  
**SOUTH HADLEY,**  
MASSACHUSETTS  
HAMPSHIRE COUNTY

PANEL 5 OF 10  
(SEE MAP INDEX FOR PANELS NOT PRINTED)

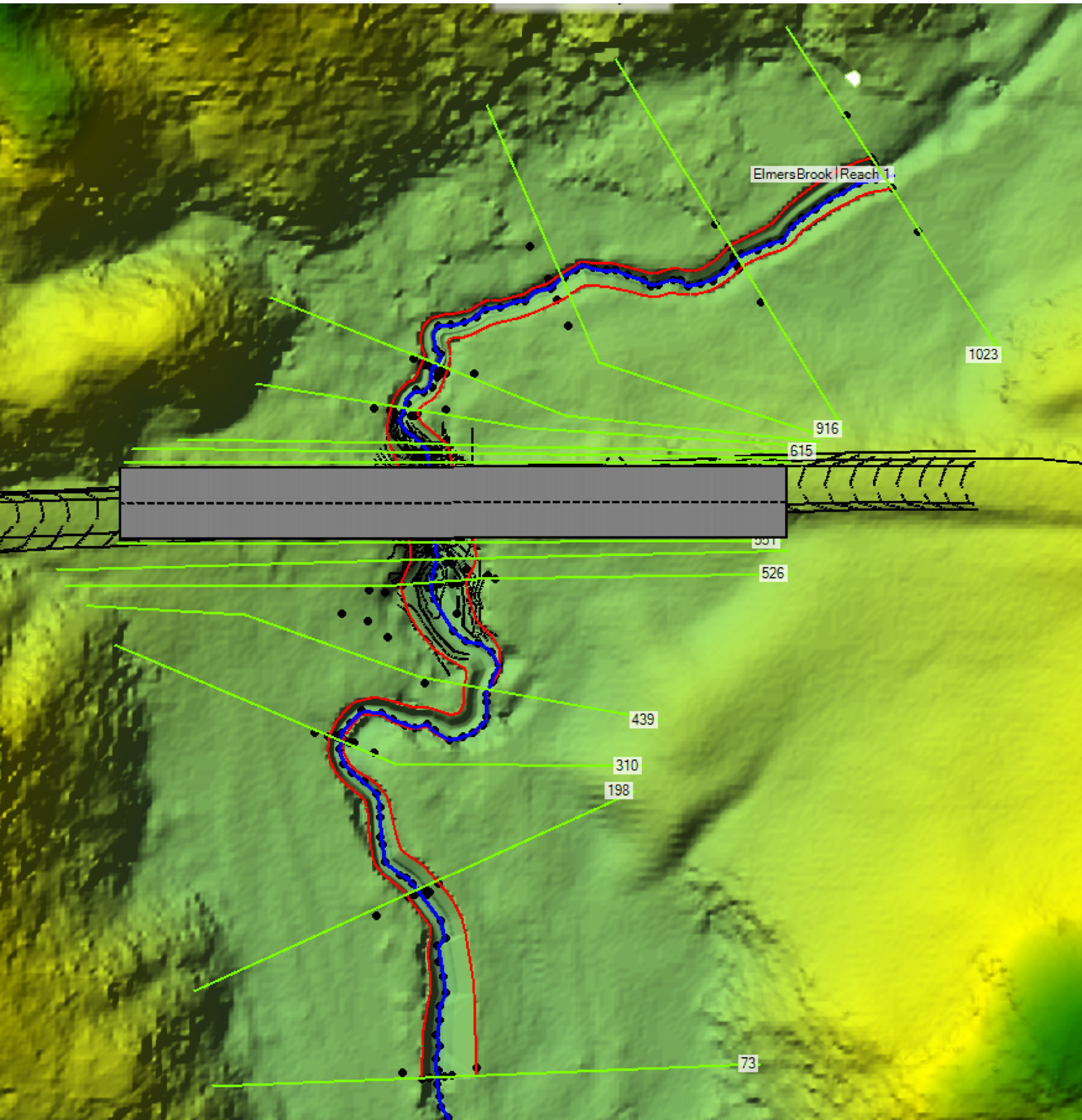
COMMUNITY-PANEL NUMBER  
250170 0005 A

EFFECTIVE DATE:  
AUGUST 15, 1979



U.S. DEPARTMENT OF HOUSING  
AND URBAN DEVELOPMENT  
FEDERAL INSURANCE ADMINISTRATION

This is an official FIRMette showing a portion of the above-referenced flood map created from the MSC FIRMette Web tool. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For additional information about how to make sure the map is current, please see the Flood Hazard Mapping Updates Overview Fact Sheet available on the FEMA Flood Map Service Center home page at <https://msc.fema.gov>.



## Appendix E

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### NCHRP Scour Calculations



Prepared By	Date	Checked By	Date	Project No
SKF	Nov-22	CMN	Dec-22	Pearl Street, South Hadley MA 20150214.B40

NCHRP 24-20 Abutment Scour Approach

Sheet No  
1 of 2

**Objective:** Calculate total abutment scour experienced by the

**Existing Bridge Abutments**

**Flow:**

**Q25 Design Scour Frequency**

**Reference:** HEC-18 Evaluating Scour at Bridges, Fifth Ed., Section 8.6.3 NCHRP 24-20 Abutment Scour Approach

The pipes are undersized, so the embankment width is almost identical to the floodplain width.

$L/b_f = 100\%$  Ratio of Embankment Length to Width of Floodplain, %

**Assumptions:**

If the projected length of the embankment is 75% or greater than the width of the floodplain, then the live-bed scour calculation is used. Otherwise, the clear-water scour calculations is use.

**L/Bf >= 75%, Use Live-Bed Scour**

**Calculate Live-Bed Scour**

$$y_c = y_1 \left( \frac{q_{2c}}{q_1} \right)^{6/7}$$

$q_b =$	278.75	Total discharge in the bridge opening, ft <sup>3</sup> /s
$W_{cs} =$	6	Width (clear span) of the bridge opening, ft <b>6 foot wide Culvert</b>
$q_{2c} =$	46.5	Unit discharge in the constricted opening accounting for non-uniform flow distribution, ft <sup>2</sup> /s
<b>Assume approach section is RS 608</b>		
$y_1 =$	7.57	Upstream flow depth, ft <b>Hydraulic depth in main channel from RS 608</b>
$v_1 =$	0.56	Upstream velocity, ft/s <b>Average velocity in main channel from RS 608</b>
$q_1 =$	4.2	Upstream unit discharge, ft <sup>2</sup> /s
$y_c =$	58.9	Flow depth including contraction scour, ft

$$y_{max} = \alpha_A y_c$$

$$y_s = y_{max} - y_0$$

$\alpha_A =$	1.10	Amplification Factor for live-bed conditions
$y_{max} =$	64.8	Maximum flow depth resulting from Abutment Scour, ft
$y_0 =$	6	Flow depth prior to scour, ft <b>Use Culvert Rise assuming Culvert is Flowing Full</b>
$y_s =$	58.8	Abutment Scour Depth, ft <b>Large scour due to pressure flow</b>

Prepared By	Date	Checked By	Date	Project No
SKF	Nov-22	CMN	Dec-22	Pearl Street, South Hadley MA 20150214.B40

$q_{2c}/q_1 = 11.0$

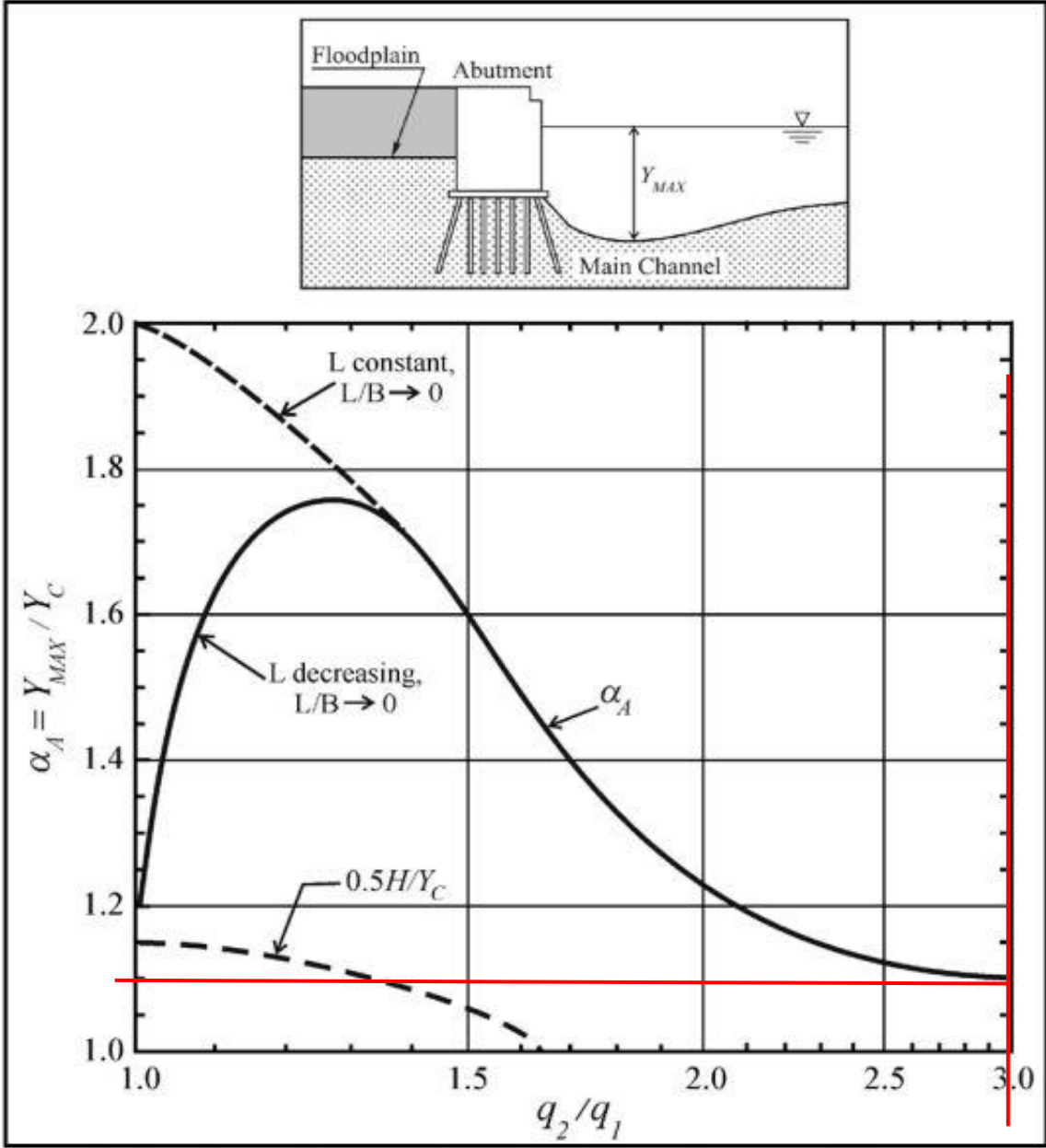


Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).

Prepared By	Date	Checked By	Date	Project No
SKF	Nov-22	CMN	Dec-22	Pearl St, South Hadley MA 20152014.B40

### NCHRP 24-20 Abutment Scour Approach

Sheet No  
1 of 2

**Objective:** Calculate total abutment scour experienced by the

**Existing Bridge Abutments**

**Flow:**

**Q50 Check Scour Frequency**

**Reference:** HEC-18 Evaluating Scour at Bridges, Fifth Ed., Section 8.6.3 NCHRP 24-20 Abutment Scour Approach

The pipes are undersized, so the embankment width is almost identical to the floodplain width.

$L/b_f = 100\%$  Ratio of Embankment Length to Width of Floodplain, %

**Assumptions:**

If the projected length of the embankment is 75% or greater than the width of the floodplain, then the live-bed scour calculation is used. Otherwise, the clear-water scour calculations is use.

**$L/B_f \geq 75\%$ , Use Live-Bed Scour**

**Calculate Live-Bed Scour**

$$y_c = y_1 \left( \frac{q_{2c}}{q_1} \right)^{6/7}$$

- $q_b = 263.26$  Total discharge in the bridge opening,  $ft^3/s$  Note: Roadway is overtopped.
- $W_{cs} = 6$  Width (clear span) of the bridge opening, ft
- $q_{2c} = 43.9$  Unit discharge in the constricted opening accounting for non-uniform flow distribution,  $ft^2/s$
- Assume approach section is RS 608
- $y_1 = 8.03$  Upstream flow depth, ft
- $v_1 = 0.66$  Upstream velocity, ft/s
- $q_1 = 5.3$  Upstream unit discharge,  $ft^2/s$
- $y_c = 49.2$  Flow depth including contraction scour, ft

$$y_{max} = \alpha_A y_c$$

$$y_s = y_{max} - y_0$$

- $\alpha_A = 1.10$  Amplification Factor for live-bed conditions
- $y_{max} = 54.1$  Maximum flow depth resulting from Abutment Scour, ft
- $y_0 = 6$  Flow depth prior to scour, ft Use Culvert Rise assuming Culvert is Flowing Full
- $y_s = 48.1$  Abutment Scour Depth, ft Large scour due to pressure flow

Prepared By	Date	Checked By	Date	Project No
SKF	Nov-22	CMN	Dec-22	Pearl St, South Hadley MA 20152014.B40

NCHRP 24-20 Abutment Scour Approach

$q_{2c}/q_1 = 8.3$

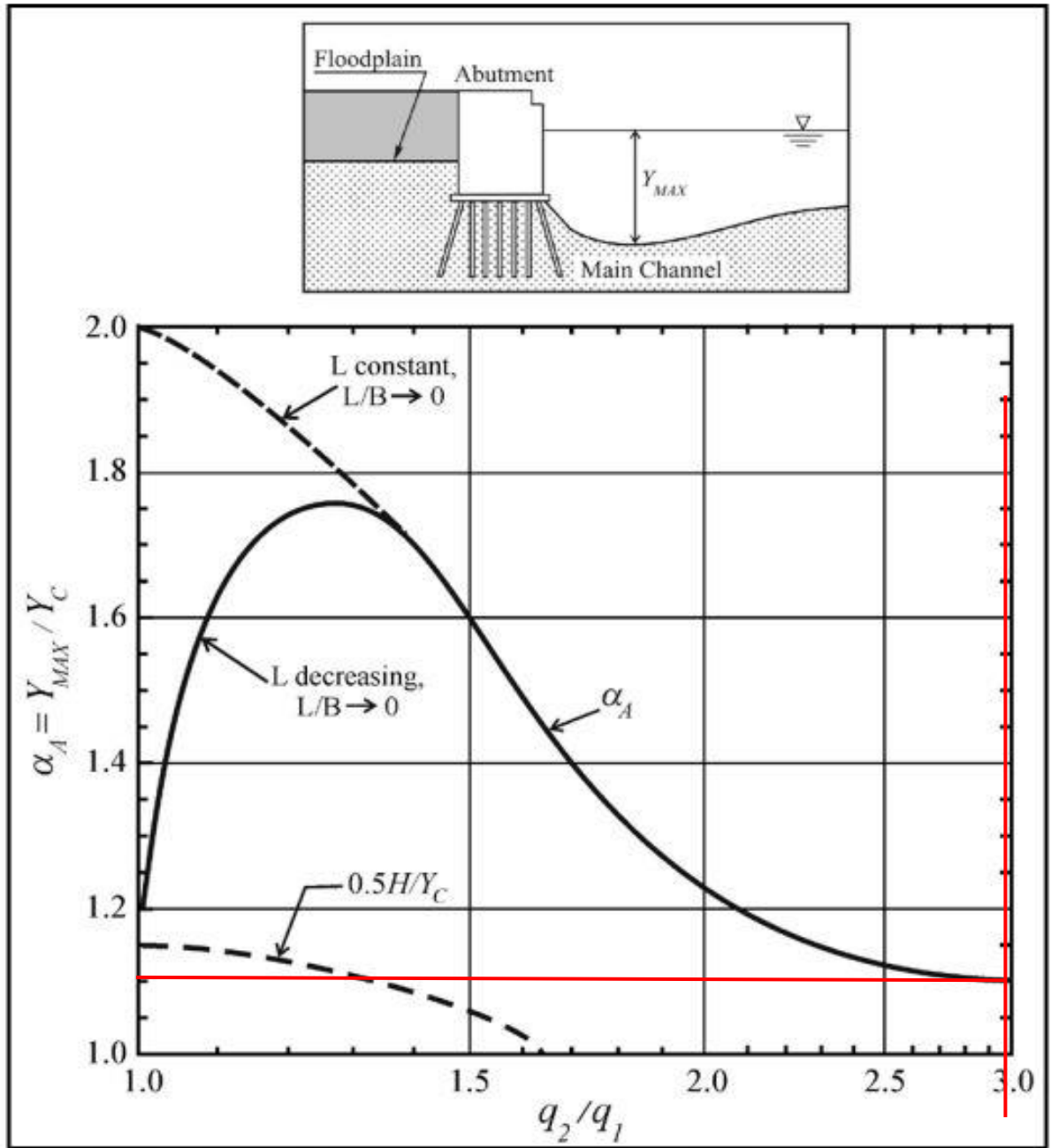


Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).



Prepared By	Date	Checked By	Date	Project No
SKF	Nov-22	CMN	Dec-22	Pearl St, South Hadley MA 20152014.B40

NCHRP 24-20 Abutment Scour Approach

Sheet No  
1 of 2

**Objective:** Calculate total abutment scour experienced by the

**Proposed Bridge Abutments**

**Flow:**

**Q25 Design Scour Frequency**

**Reference:** HEC-18 Evaluating Scour at Bridges, Fifth Ed., Section 8.6.3 NCHRP 24-20 Abutment Scour Approach

$L/b_f = 100\%$  Ratio of Embankment Length to Width of Floodplain, %

**Assumptions:**

If the projected length of the embankment is 75% or greater than the width of the floodplain, then the live-bed scour calculation is used. Otherwise, the clear-water scour calculations is use.

**L/Bf >= 75%, Use Live-Bed Scour**

**Calculate Live-Bed Scour**

$$y_c = y_1 \left( \frac{q_{2c}}{q_1} \right)^{6/7}$$

- $q_b = 414.01$  Total discharge in the bridge opening, ft<sup>3</sup>/s
- $W_{cs} = 16$  Width (clear span) of the bridge opening, ft
- $q_{2c} = 25.9$  Unit discharge in the constricted opening accounting for non-uniform flow distribution, ft<sup>2</sup>/s
- Assume approach section is RS 608*
- $y_1 = 3.22$  Upstream flow depth (Headwater Depth), ft
- $v_1 = 3.2$  Upstream velocity, ft/s
- $q_1 = 10.3$  Upstream unit discharge, ft<sup>2</sup>/s
- $y_c = 7.1$  Flow depth including contraction scour, ft

$$y_{max} = \alpha_A y_c$$

$$y_s = y_{max} - y_0$$

- $\alpha_A = 1.13$  Amplification Factor for live-bed conditions
- $y_{max} = 8.0$  Maximum flow depth resulting from Abutment Scour, ft
- $y_0 = 4.18$  Flow depth prior to scour, ft
- $y_s = 3.8$  Abutment Scour Depth, ft

Prepared By	Date	Checked By	Date	Project No
SKF	Nov-22	CMN	Dec-22	Pearl St, South Hadley MA 20152014.B40

NCHRP 24-20 Abutment Scour Approach

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2 of 2

$q_2/q_1 = 2.5$

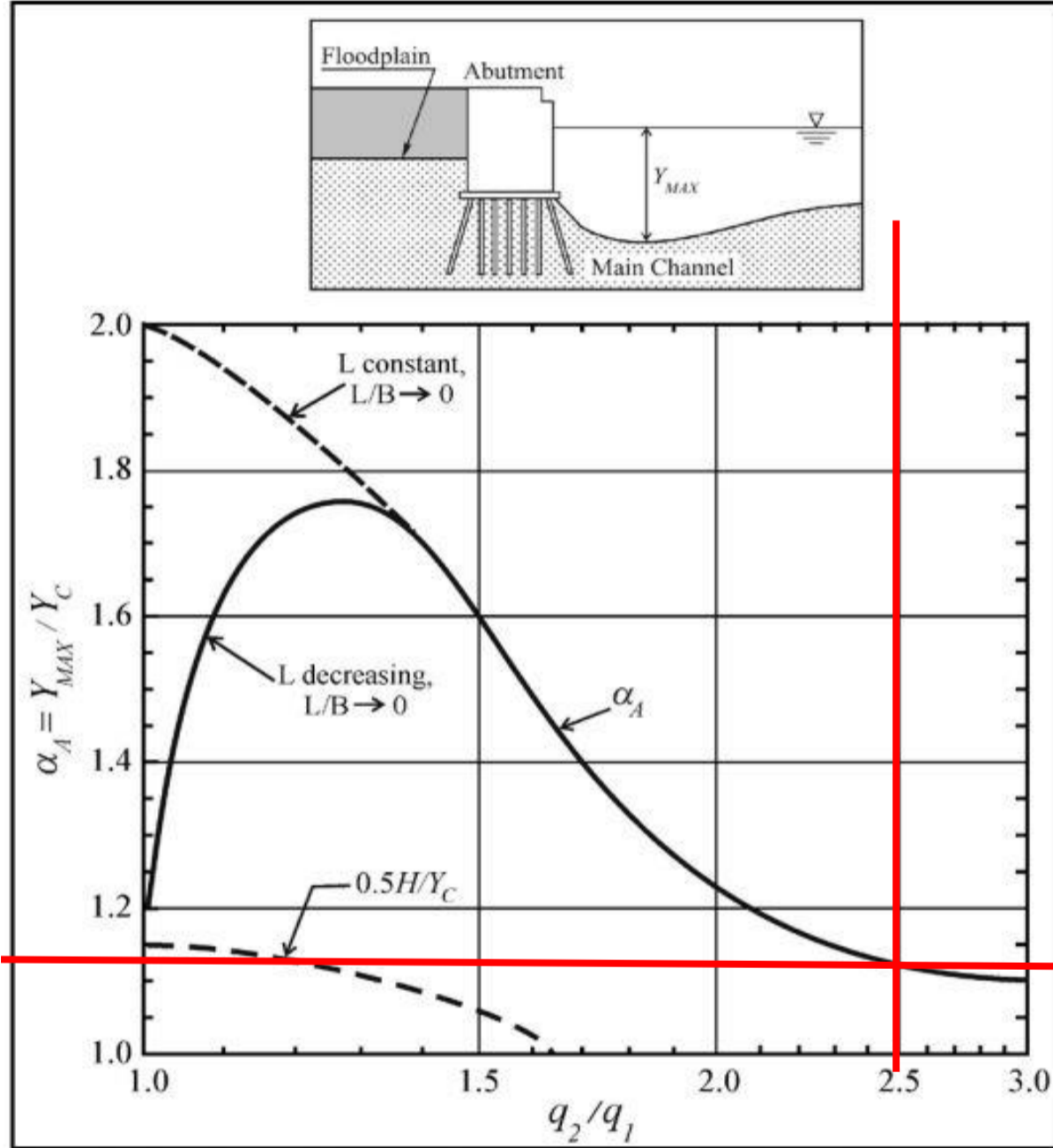


Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).



Prepared By	Date	Checked By	Date	Project No
SKF	Nov-22	CMN	Dec-22	Pearl St, South Hadley MA 20152014.B40

NCHRP 24-20 Abutment Scour Approach

Sheet No  
1 of 4

**Objective:** Calculate total abutment scour experienced by the

**Proposed Bridge Abutments**

**Flow:**

**Q200 Check Scour Frequency**

**Reference:** HEC-18 Evaluating Scour at Bridges, Fifth Ed., Section 8.6.3 NCHRP 24-20 Abutment Scour Approach

$L/b_f = 100\%$  Ratio of Embankment Length to Width of Floodplain, %

**Assumptions:**

If the projected length of the embankment is 75% or greater than the width of the floodplain, then the live-bed scour calculation is used. Otherwise, the clear-water scour calculations is use.

**L/Bf >= 75%, Use Live-Bed Scour**

**Calculate Live-Bed Scour**

$$y_c = y_1 \left( \frac{q_{2c}}{q_1} \right)^{6/7}$$

- $q_b = 531.27$  Total discharge in the bridge opening, ft<sup>3</sup>/s
- $W_{cs} = 16$  Width (clear span) of the bridge opening, ft
- $q_{2c} = 33.2$  Unit discharge in the constricted opening accounting for non-uniform flow distribution, ft<sup>2</sup>/s
- Assume approach section is RS 608*
- $y_1 = 3.88$  Upstream flow depth (Headwater Depth), ft
- $v_1 = 3.2$  Upstream velocity, ft/s
- $q_1 = 12.4$  Upstream unit discharge, ft<sup>2</sup>/s
- $y_c = 9.0$  Flow depth including contraction scour, ft

$$y_{max} = \alpha_A y_c$$

$$y_s = y_{max} - y_0$$

- $\alpha_A = 1.12$  Amplification Factor for live-bed conditions
- $y_{max} = 10.1$  Maximum flow depth resulting from Abutment Scour, ft
- $y_0 = 4.58$  Flow depth prior to scour, ft
- $y_s = 5.5$  Abutment Scour Depth, ft

Prepared By	Date	Checked By	Date	Project No
SKF	Nov-22	CMN	Dec-22	Pearl St, South Hadley MA 20152014.B40

NCHRP 24-20 Abutment Scour Approach

Sheet No  
2 of 2

$q_{2c}/q_1 = 2.7$

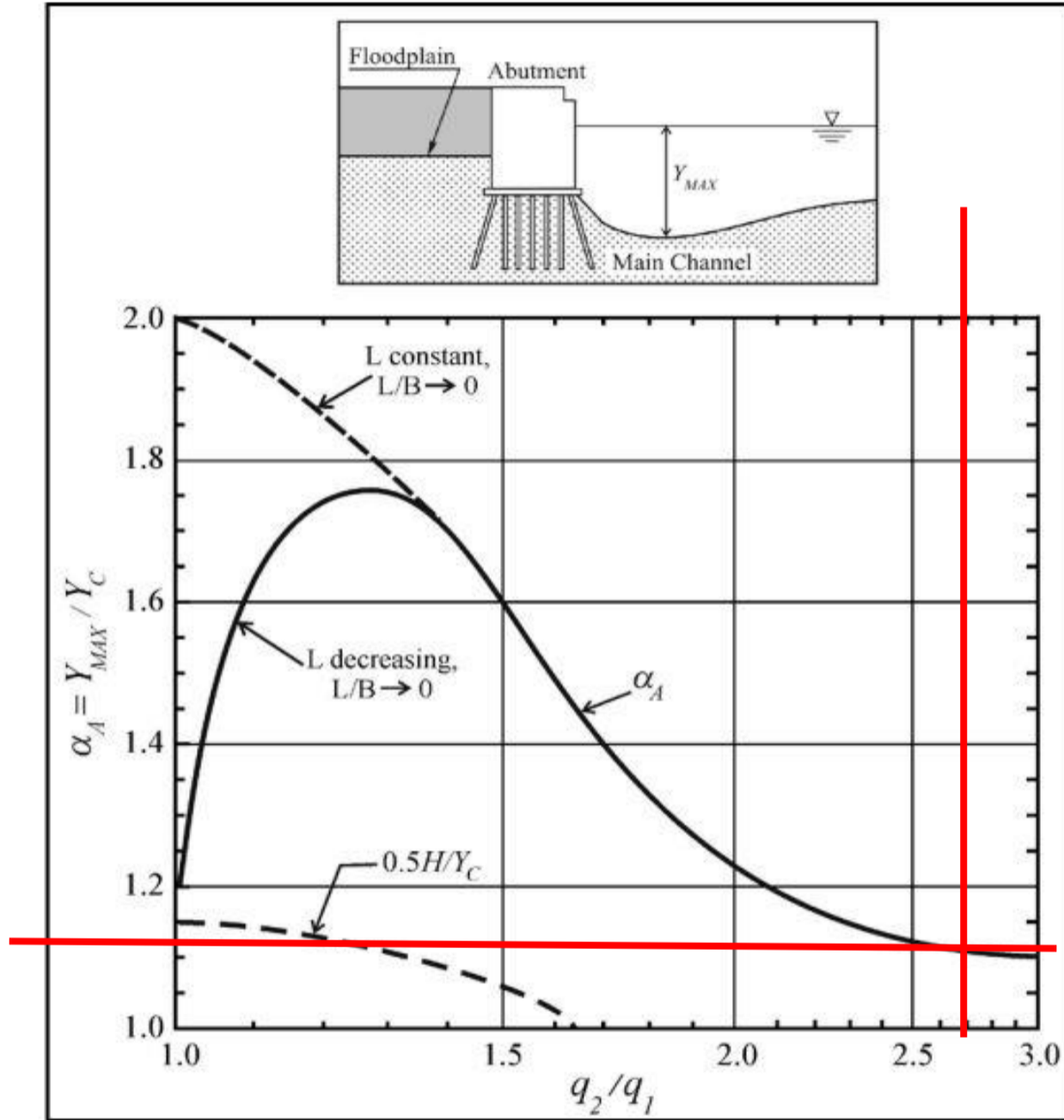


Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).