Nature-Based Solutions for Flood Resiliency
Trout Brook

City of Brockton
Brockton, Massachusetts

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FUSS & O'NEILL

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Executive Summary

In 2019 the City of Brockton received a Municipal Vulnerability Preparedness (MVP) Action Grant from the Massachusetts Executive Office of Energy and Environmental Affairs to study risks to infrastructure, environment, and residents resulting from flooding events in the City and to identify solutions to reduce those risks and increase flood resiliency. The majority of the project focused along Salisbury Brook and the Salisbury Plain River. Through modeling of those watercourses, it was ultimately determined that the Trout Brook watershed also plays a significant role in the patterns of flooding experienced in the City and improvements in this area could be key to a City-wide solution. This report documents the process and findings of a modeling study focused on Trout Brook, and presents recommendations for nature-based approaches that increase decrease flooding risk, and proactively increase resilience and provide co-benefits that improve public access to the river and provide green space within the Trout Brook corridor and surrounding neighborhoods.

Project Overview

The flood resiliency effort along Trout Brook is being designed to integrate with ongoing planning efforts by the City of Brockton to redevelop the abandoned CSX railyard that is located between Elliot Street and Court Street and bisected by Trout Brook. A broad, restored riparian corridor along Trout Brook through the railyard would be flanked by commercial and residential development areas with the intent of attracting new businesses and investment to the City, while simultaneously incorporating green infrastructure and nature-based solutions for improved flood resiliency, stormwater management, and green space amenities. The resiliency improvements along the brook will reconnect Trout Brook with its historic floodplain through the former CSX railyard and downstream of Court Street where a culverted section of the brook will be daylighted and reconnected to floodplain on adjacent City property. The capacity of an undersized culvert at Court Street will also be increased, and selected residential properties along Riverside Street (upstream of Elliot Street) that have experienced repetitive losses will be acquired to further enhance flood storage capacity.

Collectively, these improvements will increase flood capacity by creating a floodable green space that provides additional flood storage capacity in the immediate vicinity of the CSX railyard as well as in upstream and downstream areas where known repetitive flooding losses have occurred. Areas of the CSX railyard which are currently within the floodplain will be removed from the inundation area of the 100-year storm under future climate conditions and protected for redevelopment. Downstream areas including significant commercial (Verizon, Evans Machine Co.), institutional (Haitian Assembly of God of Brockton), and residential properties will also be removed from the projected future 100-year inundation area. The flood resiliency project will also allow for creation of a walkable green corridor to create continuous public green space along the brook as a public amenity, providing the community with both a nature-based solution to safely store water during flood events and enhanced connectivity and walkable access to recreation opportunities within the surrounding neighborhoods.

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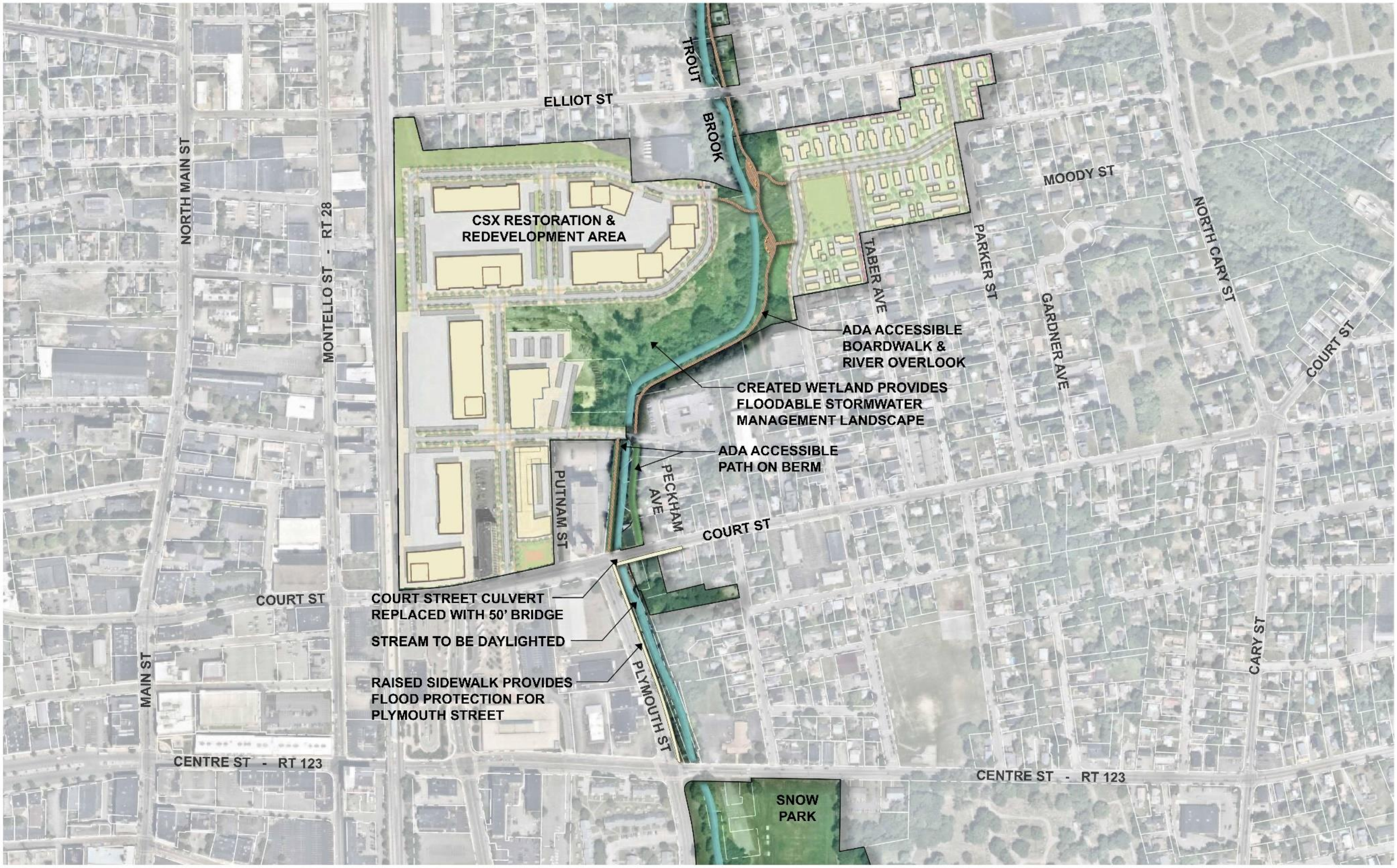

CONCEPTUAL SITE PLAN

Flood Prone Areas & Projected Climate Impacts

Under existing conditions, buildings in and around the CSX railyard and just upstream of Court Street start to become flooded during storms as small as the 2-year event (that is a storm of such magnitude that is expected to occur with 50% probability in any given year, or once, on average, every 2 years). During larger storm events, the flooding becomes more severe in this area. There are several buildings and multiple roads that are overtopped during the 100-year storm event. The existing culvert at Court Street is too small to accommodate the 100-year storm, and water backs up, causing Court Street to be overtopped by 1.5 feet of water. This also causes Plymouth Street to become inundated.

These conditions are expected to worsen under future climate change conditions, which will bring larger, more intense, and more frequent storms. Under projected future climate conditions, flooding at Court Street will increase to 2.0 feet deep, and the areas of projected flooding will expand as shown in the figure on the right. At the CSX railyard, which has been the focus of planning efforts with the intent of redeveloping the site for mixed commercial and residential use, both current and future conditions will result in significant flooding during the 100-year storm (up to 1.0 foot deep during existing conditions and up to 3.5 feet deep under the projected future conditions). Additionally, there are several residential properties in the neighborhood around the CSX railyard that have experienced repetitive losses due to flooding.

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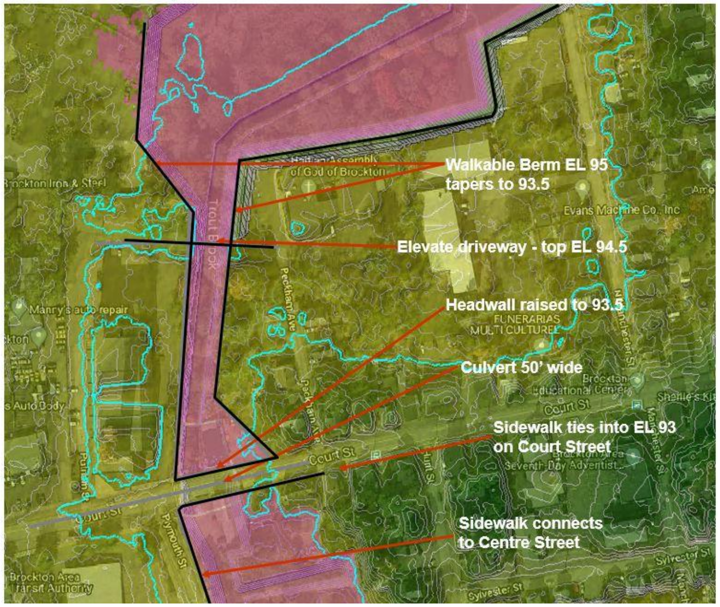
Recommended Nature-Based Approach for Reduced Flooding

Nature-based solutions focus on restoring and/or enhancing natural habitat and flood storage functions of pond or floodplain areas to increase flood storage and lower flood elevations. Restoration techniques include excavation to increase floodplain storage, widening the river channel in areas where development has resulted in encroachment into the river's natural floodplain, daylighting buried stream channels, and right-sizing culverts to provide adequate capacity to safely pass storm flows and debris without restriction.

This project identified the following suite of nature-based solutions to reduce flooding conditions along Trout Brook, while simultaneously advancing the City's planning and redevelopment goals, and paving the way for increased green space and connectivity along the Trout Brook corridor:

- Acquire CSX railyard (163-192R) and adjacent parcels (Parcels 163-044R and 163-007) and excavate 8 acres to create a restored riparian corridor and stormwater management landscape for flood storage and walkable green space within the future redevelopment site.
- Enlarge the existing 19.2-foot wide culvert under Court Street to a 50-foot wide span to eliminate backwater flooding and road overtopping.
- Acquire 188 and 189 Court Street (Parcels 163-015 and 151-030) to allow for enlargement of the culvert and daylighting of Trout Brook where it runs under the existing pavement on Parcel 151-030.
- Construct a 2.5-foot to 3.5-foot tall walkable berm from Court Street north to the CSX railyard, simultaneously providing flood protection to properties east of the brook and generating space for an ADA connector path.
- Acquire residential properties upstream of the CSX railyard that cannot be protected from flooding through other means.



Key elements of the recommended nature-based approach to reduce flooding along Trout Brook. Projected 100-year flood boundary without improvements (blue line) and with improvements (pink shading).

- Raise the driveway crossing north of Court Street and the sidewalk along Plymouth Street to prevent roadway overtopping during the projected 100-year storm.

  While more design and analysis is required to refine costs, the preliminary estimated order of magnitude cost range for this suite of solutions, including property acquisitions, design, and construction, is $17.2M to $26.1M. A significant portion of this cost would be offset by resale of the developable portions of the CSX railyard (~$5.1M) and subsequent generation of future tax revenues.

PROPOSED BOARDWALK THROUGH CSX RESTORATION AREA

VIEW SOUTH TOWARD COURT STREET

1 Project Background and Purpose

Figure 1: Aerial View of Salisbury Brook, Salisbury Plain River, and Trout Brook

Trout Brook is a tributary to the Salisbury Plain River (Figure 1) that contributes a significant amount of water downstream during large storm events, with subsequent flooding impacts for the south end of the City. Fuss & O'Neill previously developed a hydraulic model for the Salisbury Brook and Salisbury Plain River systems and identified nature-based solutions to address flooding along those waterways as part of the City's FY19 MVP Action Grant. In that model, the Trout Brook tributary was initially modeled as an unsteady inflow hydrograph applied directly at the confluence with the Salisbury Plain River. This approach did not take into account the routing of the terrain, which would be expected to delay the timing and magnitude of peak flows with hydraulic restrictions (bridges, culverts, etc.) in place.

Thus, once it became evident that stormwater inputs from Trout Brook could be critical to the City's overall flood resiliency strategy, the modeling project was expanded to include more detailed analysis of Trout Brook. The model presented here is intended to develop a more accurate and refined model specific to the Trout Brook watershed to better predict the flow contributions from Trout Brook. This approach in turn allows for investigation of nature-based solutions for flood resiliency within the Trout Brook watershed that may have positive benefits for reducing flooding within the watershed, as well as along the downstream reaches of the Salisbury Plain River.

This modeling and flood resiliency effort along Trout Brook was also designed to integrate with ongoing planning efforts by the City to redevelop the abandoned CSX railyard that is located between Elliot Street and Court Street and bisected by Trout Brook. A master plan concept for the area prepared by RKG Associates (2019) depicts a stormwater management landscape to be created along Trout Brook. This stormwater management corridor would be flanked by commercial and residential development areas with the intent of attracting new businesses and investment to the City, while simultaneously incorporating green infrastructure and nature-based solutions for improved flood resiliency, stormwater management, and green space amenities. Figure 2 below shows one proposed layout presented by RKG for the development plan for the abandoned railyard. The left side of the image depicts future commercial buildings, and the right shows potential areas for developing apartment complexes or other single family residential structures.

Solutions targeted in this study were focused around incorporation of the area identified for stormwater management into a larger floodplain reconnection project to provide additional flood storage capacity in the immediate vicinity of the CSX railyard as well as in upstream and downstream areas where known repetitive flooding losses have occurred. Flood resiliency projects in these areas could potentially be integrated into a green corridor project to create continuous public green space along the brook as a public amenity, providing the community with a nature-based solution to safely store water during flood events while creating walkable access and recreation opportunities from the surrounding neighborhoods.

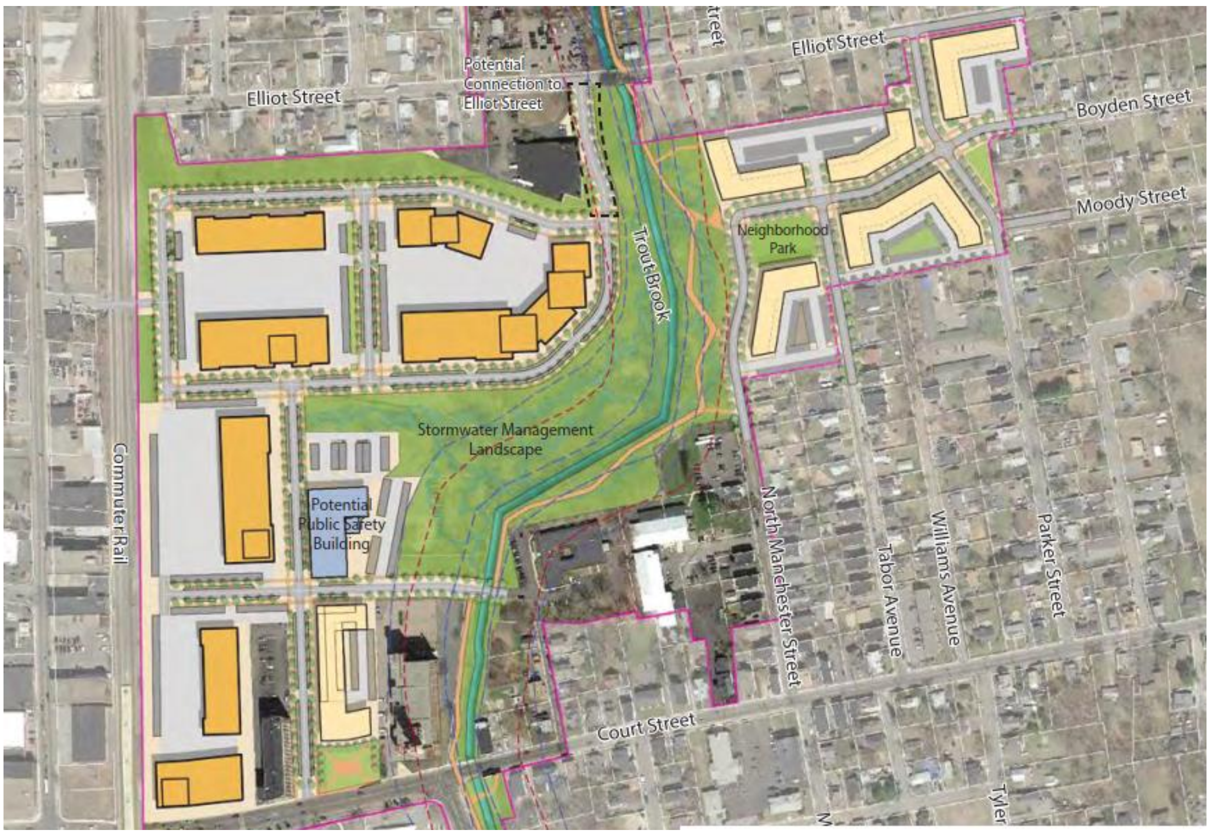


Figure 2: CSX Redevelopment Project Plan (Source: 2019 CSX Site Master Plan by RKG Associates)

2 Model Setup

2.1 Hydrologic Model

A hydrologic model for Trout Brook was developed using the U.S Army Corps of Engineers HEC-HMS version 4.7.1 software. The Soil Conservation Service (SCS) Curve Number (CN) methodology was used to represent the hydrologic losses for each sub-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.

2.1.1 Design Storms

The January 2020 model created by Fuss & O'Neill for Salisbury Brook showed that floodplain restoration would have the most significant flood reduction benefits for the 2- and 10-year storms. Based on these results and the similarities between the project areas, we expected to see a similar pattern for the Trout Brook watershed. It is also important to study the effects of a larger storm event to determine the inundation impacts to buildings and roadways. Therefore, the 2-, 10-, and 100-year events were considered as the design storms for this analysis. The meteorological model in HEC-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 event and are shown in Table 1.

Table 1: Design Storm Normal Depths

Design Storm	Precipitation Depth (in)
2-year	3.37
10-year	5.10
100-year	7.84

2.1.2 Watershed Delineation

The Trout Brook watershed was delineated using the StreamStats online webtool, a commonly used program developed by the United States Geological Survey (USGS). The outlet point was selected at the confluence of Trout Brook with the Salisbury Plain River. The total watershed has an area of 6.97 sq mi, and was broken into 4 sub-watersheds based on tributary locations and significant structures. Trout Pond Dam sub-watershed captures the northern portion of the watershed (2.58 sq mi). The Cary Brook sub-watershed represents the significant tributary inflows into Trout Brook and is located just north of Puffer Playground (1.34 sq mi). Ames Street is hydraulically restricted by a long undergrounded culvert and the area draining to the Ames Street culvert was selected as the third sub-watershed (1.72 sq mi). The remaining area of the Trout Brook watershed is represented by the "Downstream" sub-watershed (1.33 sq mi). Figure 3 represents the Trout brook sub-watershed boundaries overlain on an aerial map.

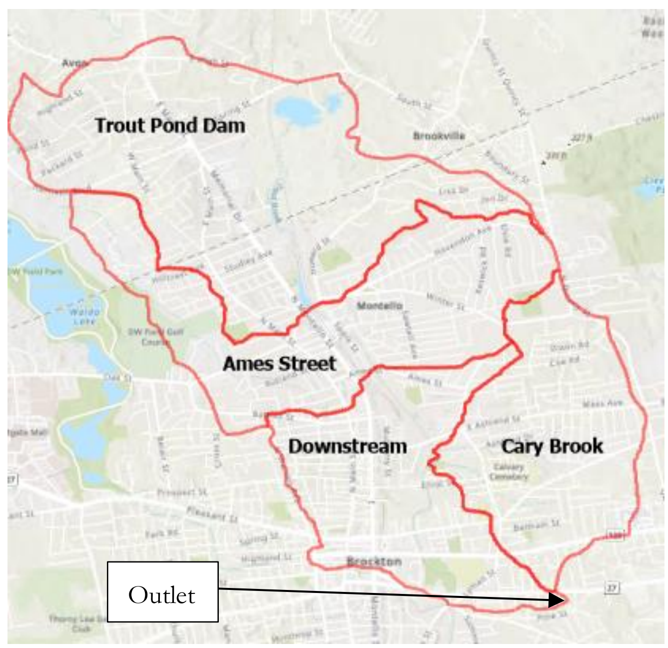


Figure 3: Trout Brook Sub-Watersheds

2.1.3 Curve Number (CN) Development

To determine the Curve Numbers for each sub-watershed, soil and land use data were obtained from the USDA Natural Resources Conservation Service (NRCS) Web Soil Survey (WSS) Database (SSURGO 2.2) and the Land Cover Land Use data (2016) was obtained from MassGIS OLIVER.

The Natural Resources Conservation Service (NRCS) classifies soils into four hydrologic groups represented as Type A, B, C, and D soils. Type A soils have high infiltration capacity and typically consist of coarse sands, while Type D soils have very low infiltration capacity, typically due to a restrictive layer or clay content. Some soils are classified as two types, such as A/D, B/D, and C/D, which reflect areas with a shallow groundwater table and infiltration capacity that is dependent on the antecedent moisture condition. These soil groups were conservatively treated as Type D in the Curve Number (CN) calculation since the hydrologic analysis is based on extreme precipitation events.

The land use data within the 2016 Land Cover Land Use dataset was used as the primary identifier, except in the cases where the land use was classified as right-of-way, unknown, or tax exempt; the land cover code was used instead in these instances. Curve numbers were assigned to the combined land cover land use dataset using guidance from table 2-2a in the USDA Urban Hydrology for Small Watersheds TR-55 document. The curve number assumptions are shown in Table 2 below. The dominant land use classification for the Trout Brook watershed is single family residential.

Table 2: Curve Number TR-55 Assumptions

Land Cover/ Land Use	Land Cover/ Land Use #	A	B	C	D	TR-55 Assumptions
Commercial	3	89	92	94	95	As-is in document
Mixed use, primarily commercial	30	89	92	94	95	Same as commercial
Industrial	4	81	88	91	93	As-is in document
Mixed use, primarily residential	10	61	75	83	87	Same single family (almost no parcels classified this way in Brockton)
Residential single family	11	61	75	83	87	Residential 1/4 acre (average size determined from parcel viewer)
Residential other	13	61	75	83	87	same single family (almost no parcels classified this way in Brockton)
Residential multi-family	12	61	75	83	87	Residential 1/4 acre – (average parcel size based on GIS parcel viewer)
Impervious	2	98	98	98	98	As-is in document
Developed Open Space	5	39	61	74	80	Good condition grass open space
Forest	6	30	55	70	77	Woods – good condition
Deciduous Forest	9	30	55	70	77	Woods – good condition
Evergreen Forest	10	30	55	70	77	Woods – good condition
Open Land	20	39	61	74	80	Good condition grass open space
Grassland	8	39	61	74	80	Good condition grass open space
Water	88	98	98	98	98	As-is in document

The composite curve numbers for each sub-watershed are shown in Table 3 with their respective drainage areas.

Table 3: Composite Curve Number for Each Sub-watershed

Sub-watershed	Drainage Area (sq mi)	Composite Curve Number
Trout Pond Dam	2.58	77.9
Ames Street	1.72	79.0
Cary Brook	1.34	75.3
Downstream	1.33	70.7

2.1.4 Snyder Methodology

The HEC-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:

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

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)

C_T and C_P are not physically-based parameters, and therefore are better determined through calibration. However, there are no stream gages near the Trout Brook watershed to calibrate the hydrologic parameters. 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 2.0 was used as an average typical value for C_T. The longest flow path and centroidal flow path were then calculated for each sub-watershed in GIS.

The HEC-RAS technical manual indicates typical values for C_P ranging from 0.4 to 0.8. To determine which value for C_P would be appropriate for the Trout Brook watershed, a single watershed model was developed in HEC-HMS. A sensitivity analysis was conducted for C_P, varying the values from 0.4 to 0.8 (in increments of 0.1). The peak flows were compared to FEMA's Flood Insurance Study (FIS) for Plymouth County, Massachusetts (November 4, 2016) for the 10 and 100-year storms (Table 4). A C_P value of 0.5 most closely reproduced the peak flows presented in the FEMA FIS, and therefore 0.5 was used for C_P each of the sub-watersheds in the detailed model.

Table 4: FEMA Peak Flow Comparisons

Design Storm	Single Basin HEC-HMS peak flow (cfs)	FEMA peak flow (cfs)
10-year	790	790
100-year	1,537	1,210

Table 5 presents the final hydrologic parameters for each of the sub-watersheds.

Table 5: Final Hydrologic Parameters

Sub-watershed	Drainage Area (sq mi)	Longest Flow Path, L (mi)	Centroidal Flow Length, L_{ca} (mi)	C_T	Peaking Coefficient (C_P)	Lag Time, T_L (hours)
Trout Pond Dam	2.58	3.0	1.1	2.0	0.5	3.1
Ames Street	1.72	2.5	0.4	2.0	0.5	2.2
Cary Brook	1.34	1.9	0.7	2.0	0.5	2.4
Downstream	1.33	2.0	1.0	2.0	0.5	2.7

2.2 Hydraulic Model

2.2.1 Existing Conditions Model Setup

To analyze the existing conditions model for Trout Brook, a 2-dimensional (2D) HEC-RAS (version 5.0.7) hydraulic model was developed. The terrain was created from a 1-meter LiDAR based Digital Elevation Model (DEM) downloaded from NOAA Coastal Data Viewer (2016 USGS CoNED Topobathymetric Model). The 2D mesh was developed using an average of 50-foot by 50-foot grid cells. The mesh was refined using breaklines along the channel and major roads using 25-foot by 25-foot cells. Manning's n values were assigned using the Land Cover Land Use dataset (2016, obtained from MassGIS OLIVER) and were assigned typical values from the HEC-RAS technical manual.

The upstream boundary condition was set by the Trout Pond Dam sub-watershed. The Cary Brook tributary sub-watershed, Ames Street sub-watershed, and the downstream sub-watershed inflow hydrographs defined by the HEC-HMS model were set as inflow boundary conditions at their respective sites (Appendix C). The bridge and road crossings were surveyed in the field by Fuss & O'Neill staff on March 11, 2021. These measurements were incorporated as SA/2D area connections in the HEC-RAS model. The model terminates approximately 3 miles downstream at the confluence of Salisbury Plain River. Figure 4 depicts the model geometry set up for existing conditions.

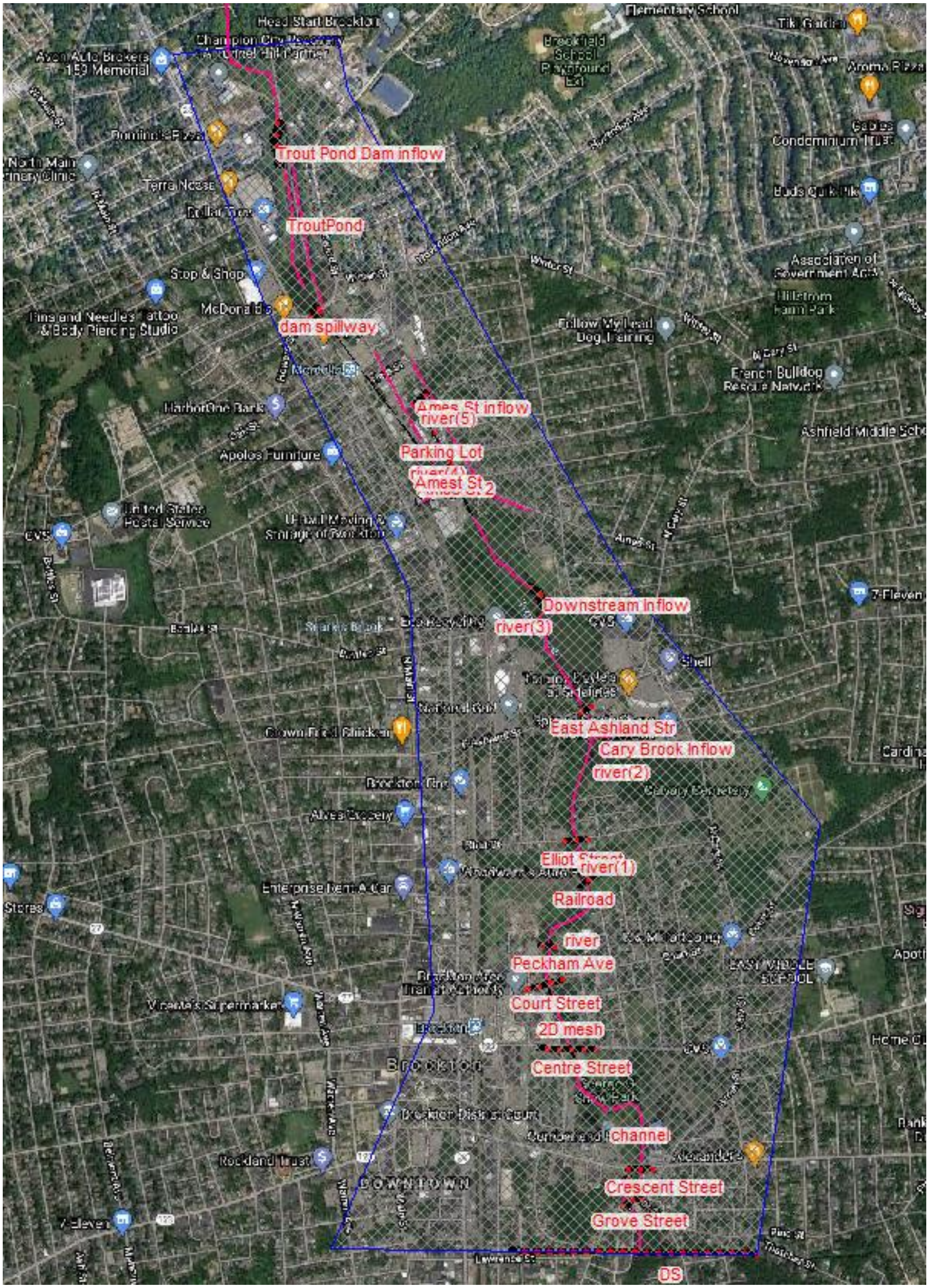


Figure 4: HEC-RAS 2D Model Geometry

2.2.2 Model Results – Existing Conditions

The results of the hydraulic analysis of the Trout Brook system indicate that flooding will occur within multiple areas throughout Trout Brook during the 2-, 10-, and 100-year storms. The frequency and extent of the flooding is described in more detail in the following sections starting with the most upstream location and working downstream.

Area 1:

The area upstream of Ames Street (Area 1) appears to experience flooding during events with a magnitude greater than or equal to the 10-year storm (Figure 5). (The 2-year storm is contained within the channel.) There are multiple factors in this area that are causing flooding.

Figure 5: Inundation Limits for Area 1

- The culvert from Trout Pond Dam discharges into the culvert that is undergrounded at Ames Street.
- There is also a culvert that runs underneath a parking lot before daylighting briefly then flowing into the Ames Street culvert.
- There is significant flow from both the dam and the inflows from the Ames Street sub-watershed.
- The limited capacity of the culverts appears to be a significant factor for elevated flooding levels at this location.
- Maximum flooding depths in this area reach approximately 3 feet for the 100-year storm.

Area 2:

Figure 6 below depicts the flooding zones downstream of Ames Street and upstream of East Ashland Street (Area 2). Most of this area is wetlands, however Tukis Park and East Ashland Street are both inundated during the 100-year storm. There are also buildings, roadways, and parking lots affected by the 100-year storm. While there is room in this area to accept some flooding without impacting structures, the limited culvert capacity at East Ashland Street cannot accommodate the 100-year storm. Maximum flooding depths on East Ashland Street reach 1.8-feet.

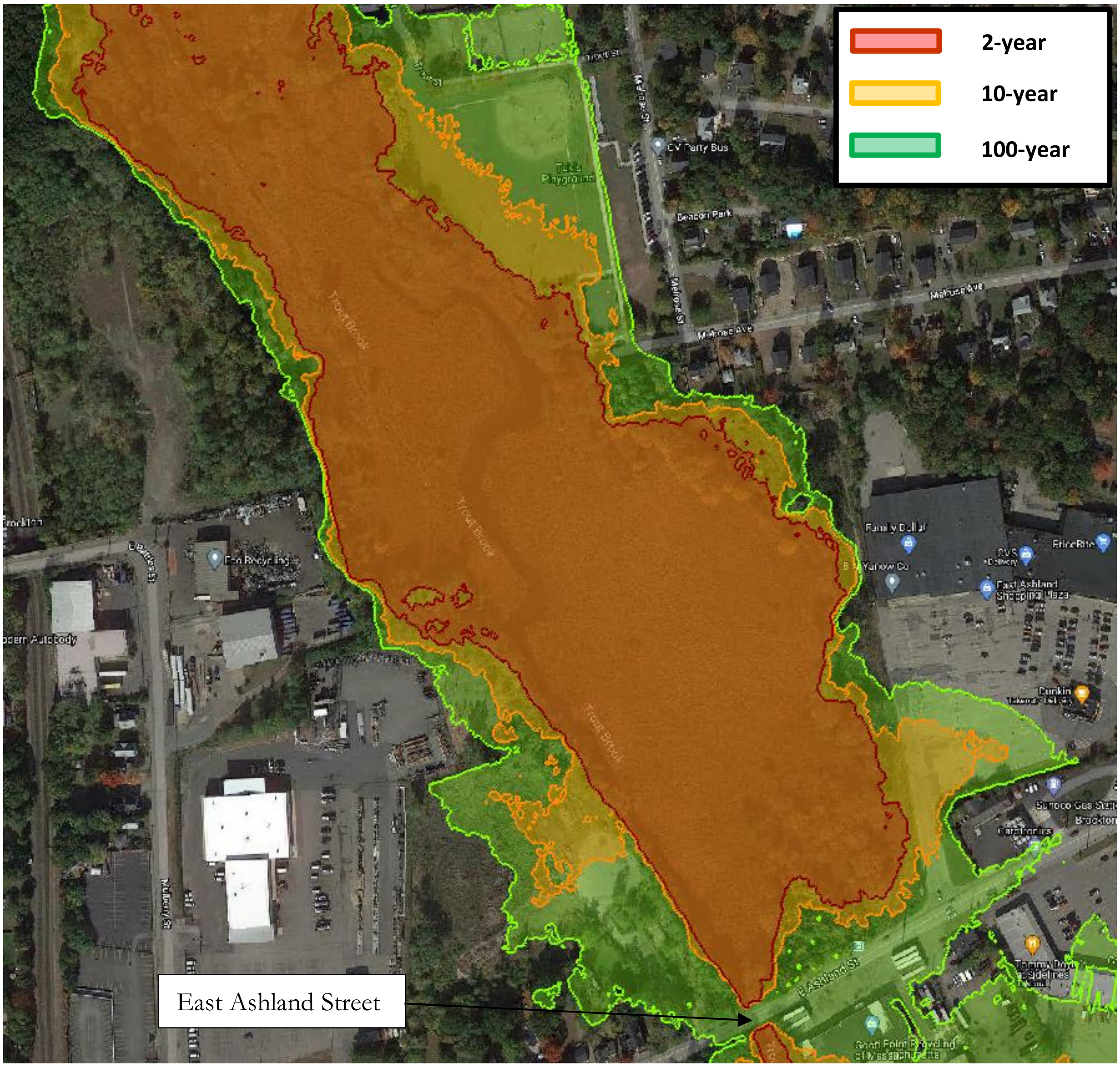


Figure 6: Inundation Limits for Area 2

Area 3:

Figure 7 below depicts the inundation limits downstream of East Ashland Street and upstream of Elliot Street (Area 3). The majority of the 2-year limits are contained within open fields and wetlands, however some businesses and roads are starting to become inundated as well as Puffer Playground. Flow from upstream combines with the flows from the Cary Brook tributary at this location.[1] The modeling indicates that the culvert capacity at Elliot Street is causing water to back up and flood this area. Average flooding depths in this area reach up to 5 feet for the 2-year storm and up to 9.5 feet for the 100-year storm. Buildings along Teele Street start to become inundated during the 2-year storm (0.5 feet) and reach up to 5-feet during the 100-year storm. Elliot Street begins to overtop (up to 1.3-feet) during the 100-year storm.

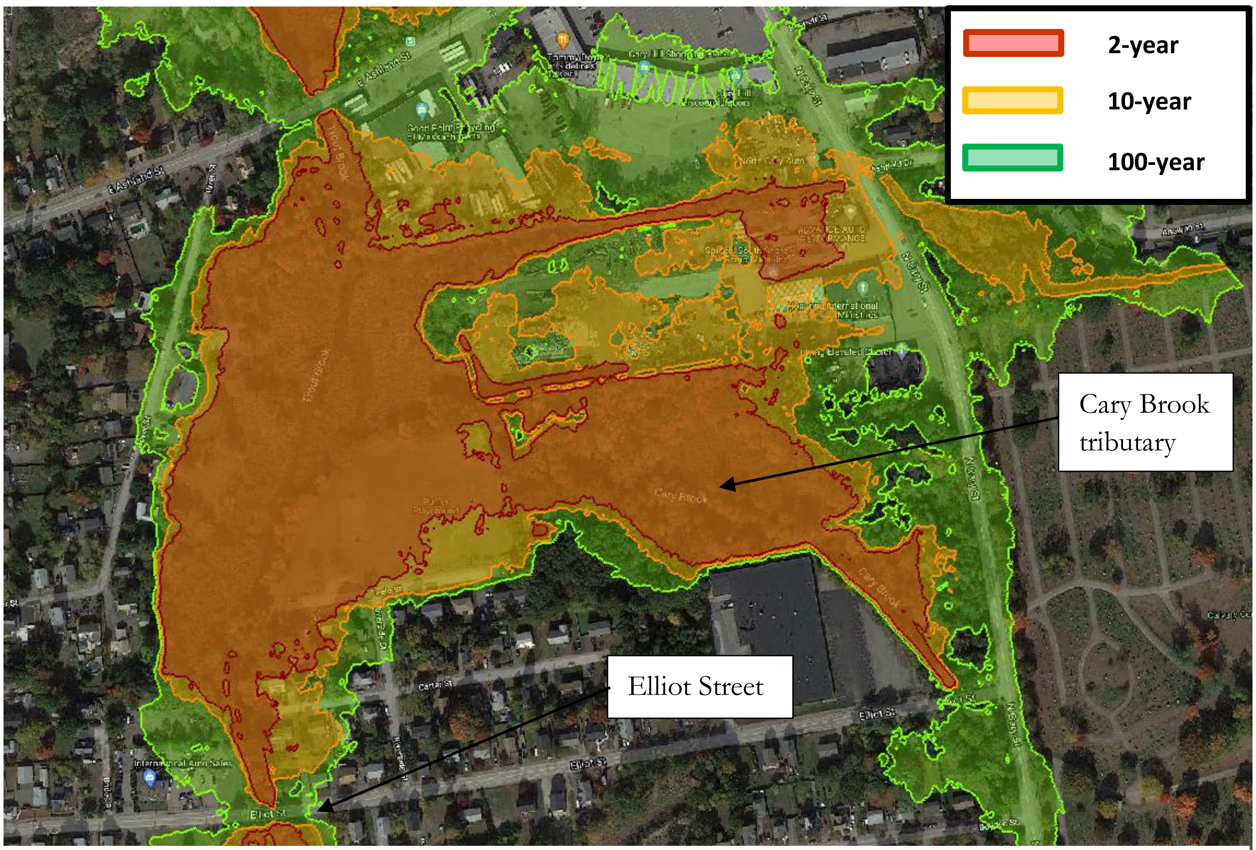


Figure 7: Inundation Limits for Area 3

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[1] Expansion of this culvert was considered during the modeling process. It was found that even increasing the culvert to a 60-foot span does not significantly improve upstream flooding because of the volume of water stored above Elliot Street.

Area 4:

Figure 8 below depicts the inundation limits downstream of Elliot Street and Upstream of Court Street (Area 4). This location contains the abandoned CSX railyard. The modeling shows that even at the 2-year storm, houses and roadways begin to flood. During larger storm events, the flooding becomes more severe in this area. There are several buildings and multiple roads that are overtopped during the 100-year storm event. The culvert at Court Street cannot accommodate the 100-year storm, and the overtopping also causes Plymouth Street to become inundated. Flooding depths in this area reach up to 0.5 feet for the 2-year storm and up to 5.5 feet for the 100-year storm. Court Street is overtopped by 1.5 feet during the 100-year storm.

Figure 8: Inundation Limits for Area 4

Area 5:

Figure 9 below depicts the inundation limits downstream of Court Street to the study limits of the Trout Brook model (Area 5). It appears that Center Street has adequate capacity to pass all design storms. While Snow Park is inundated, there are no roadways or other structures that are impacted by any of the design storms in this area or further downstream. Flooding depths in this area reach up to 0.8 feet for the 2-year storm and up to 4 feet for the 100-year storm.

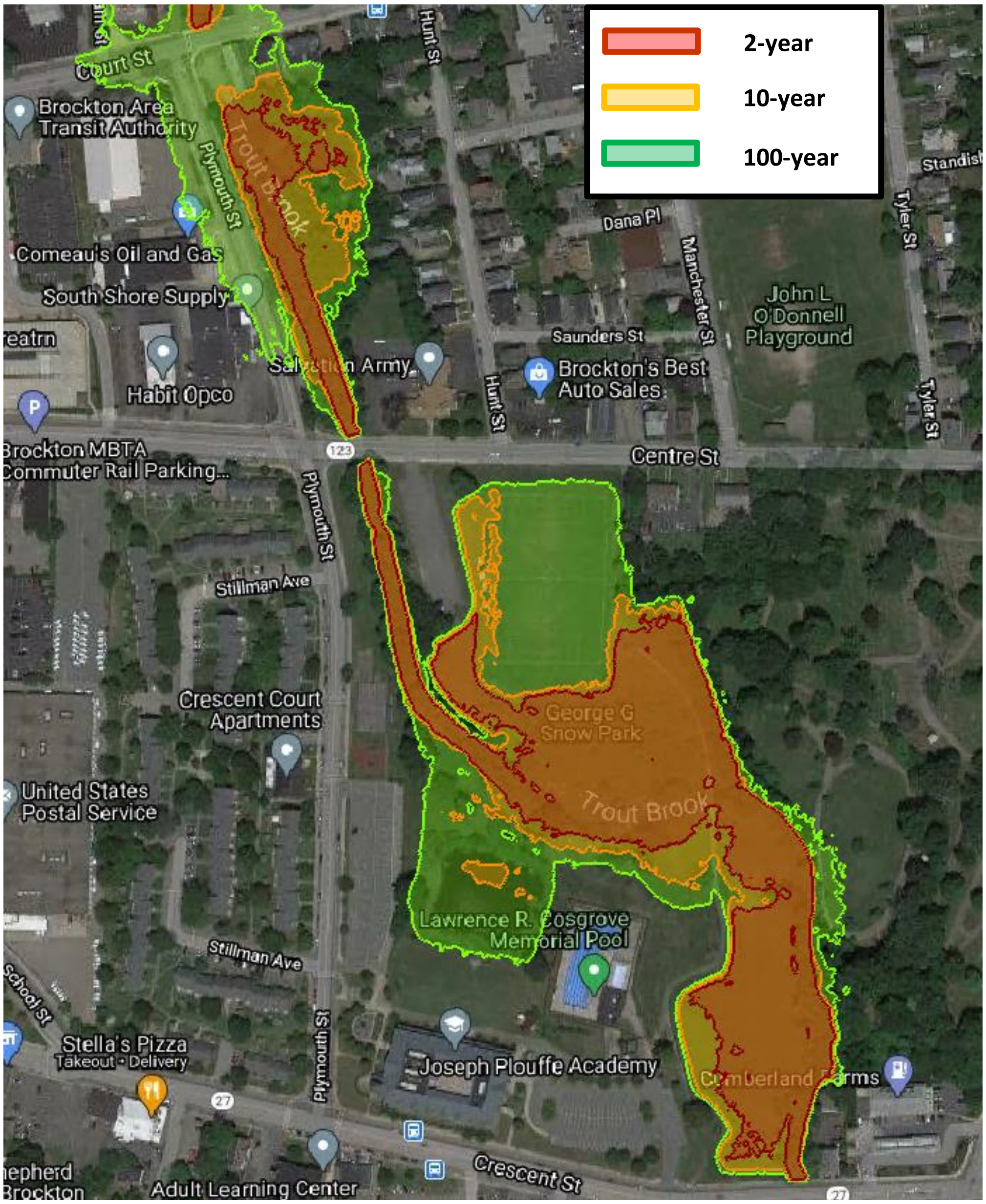


Figure 9: Inundation Limits for Area 5

Peak Flows at Confluence with Salisbury Plain River:
The current modeling approach utilizes terrain routing to increase the accuracy of estimated peak flows specific to the Trout Brook watershed. This method yields peak flows at the confluence of Trout Brook and Salisbury Plain River that are on average 30% lower than those originally estimated in the January, 2020 model for the same confluence point (Table 6). Because inflows from Trout Brook were found to have a significant role in downstream flooding along the Salisbury Plain River, the more accurate, updated flows from this analysis should be used to refine the modeled flood reductions at the proposed downstream restoration areas along the Salisbury Plain River should those projects move forward to design. It is expected that flood reduction benefits may be higher than originally predicted when this updated data is taken into account.

Table 6: Peak Flow Comparisons from January 2020 Model to Current Model

	Peak Flows (cfs)		
	2-year	**10-year**	**100-year**
January 2020 model	460	750	1,300
Updated model	285	550	935
Percent Reduction	38%	27%	28%

2.2.3 Existing Conditions with Projected Flows

To assess the impacts that projected increased precipitation caused by climate change would have on flooding experienced throughout the Trout Brook riverine system during existing conditions, a flood magnification factor of 1.21 was applied to approximate projected impacts that each flood event will have in 2040. According to USGS Scientific
Investigations Report 2012-5109, average flood magnification factors of 1.06, 1.13, and 1.21 were computed from local stream gauge data for 10-, 20-, and 30-year projections, respectively, out from 2010.

The existing conditions were run in the HEC-RAS model with the 1.21 magnification factor applied to the rainfall runoff hydrographs generated by each contributing sub-watershed (for each analyzed flood event). A depiction of existing conditions versus projected future conditions in and around the CSX railyard area for the 100-year storm is provided on Figure 10. The area on the left of the image where the City's redevelopment plan calls for future commercial buildings to be built is more severely inundated in the projected future condition, and flooding depths reach up to 2 feet in this location. On the right side of the image, the neighborhood surrounding Moody Street also experiences more severe flooding under future conditions. Court Street is overtopped by 2 feet of water (compared to 1.5 feet without climate change impacts). The driveway crossing upstream of Court Street that ties into Peckham Ave begins to overtop during the projected future 100-year storm; this crossing does not overtop during existing conditions.

The alternatives considered for this project account for the projected flows under climate change and are explained in more detail in the following sections.

Figure 10: Existing Conditions 100-year and Projected 100-year

3 Alternatives Considered

To address the areas that are prone to flooding along Trout Brook, three alternatives were developed and analyzed in HEC-RAS.

Alternative 1 utilizes the green space presented by RKG associates in their Site Master Plan for redeveloping the CSX railyard area. The red boundary shown in Figure 11 depicts the limits of floodplain restoration for this alternative. This creates an 8-acre floodplain corridor that is approximately 9-feet lower than the surrounding landscape which is preserved for redevelopment.

Alternative 2 is closely related to Alternative 1. The area marked for residential buildings on the right side of Figure 11 (outlined in blue) was graded as additional flood storage and added to the area used for Alternative 1. This option decreases the available redevelopment space by approximately 7 acres. Similarly to Alternative 1, the bottom portion of the landscape would be set to the same elevation as Alternative 1. The floodplain would tie back into existing elevations on the east side of the restoration area.

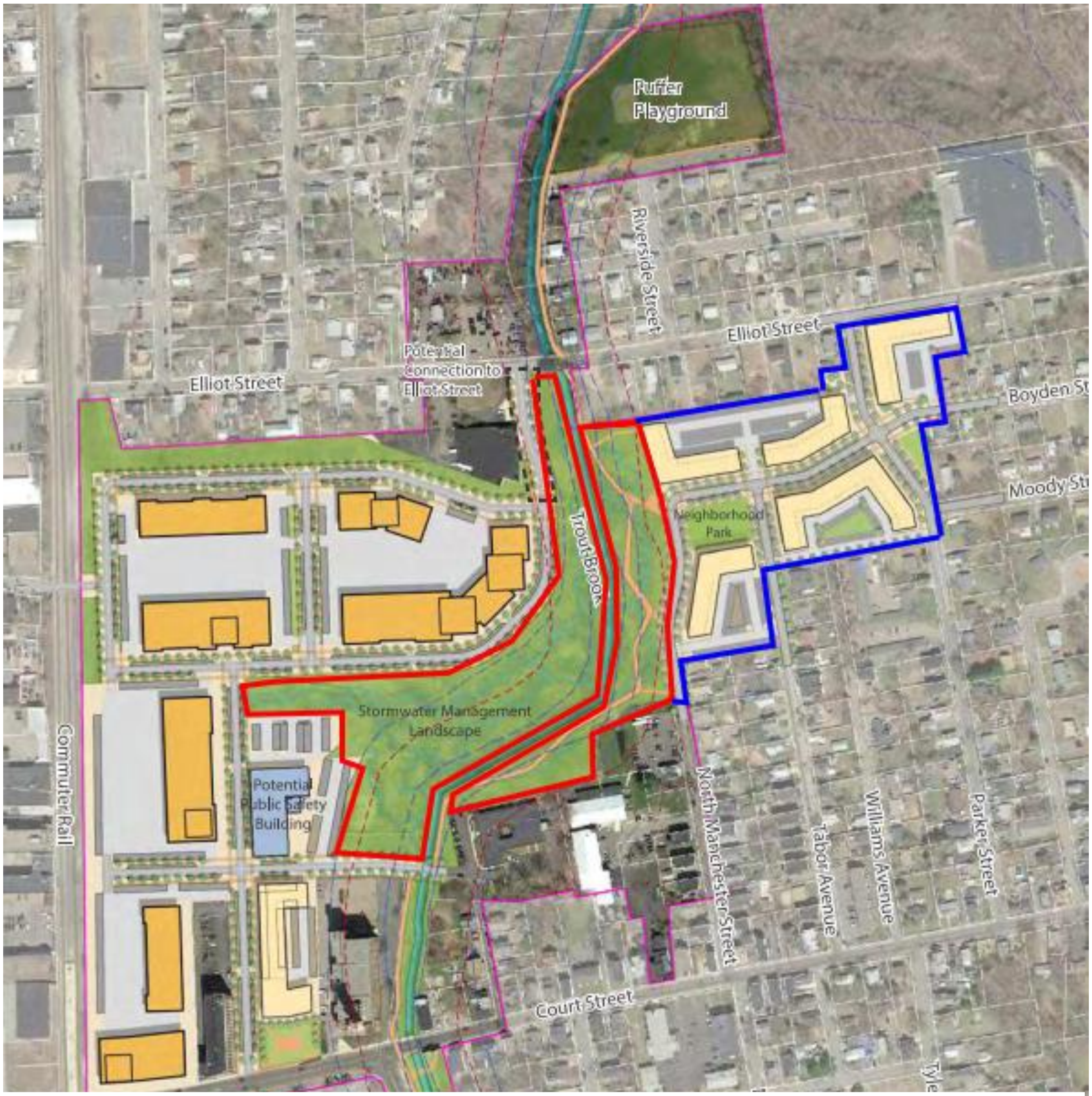


Figure 11: Floodplain Restoration Limits for Alternatives 1 and 2 (Graphic modified from 2019 CSX Site Master Plan by RKG Associates)

Alternative 3 expanded the floodplain restoration area further upstream and downstream, assessing other potential sites along the Trout Brook corridor to mitigate flooding. This alternative looked at City-owned parcels and also considered buy-outs of privately-owned parcels. The sites that were considered in this alternative are as follows (from upstream to downstream):

- There are two City-owned parcels connected to other undeveloped parcels along Trout Brook north of the CSX yard and in the vicinity of Tukis Park (Figure 12). The privately-owned parcel is targeted for development, therefore grading was limited to an area within a 100-foot offset from the channel to allow for future development in this parcel. The other parcels were graded to the lowest elevation possible to maximize flood storage and tied back in to existing elevations. Tukis Park was regraded at a slightly higher elevation to limit frequent flooding in this area.

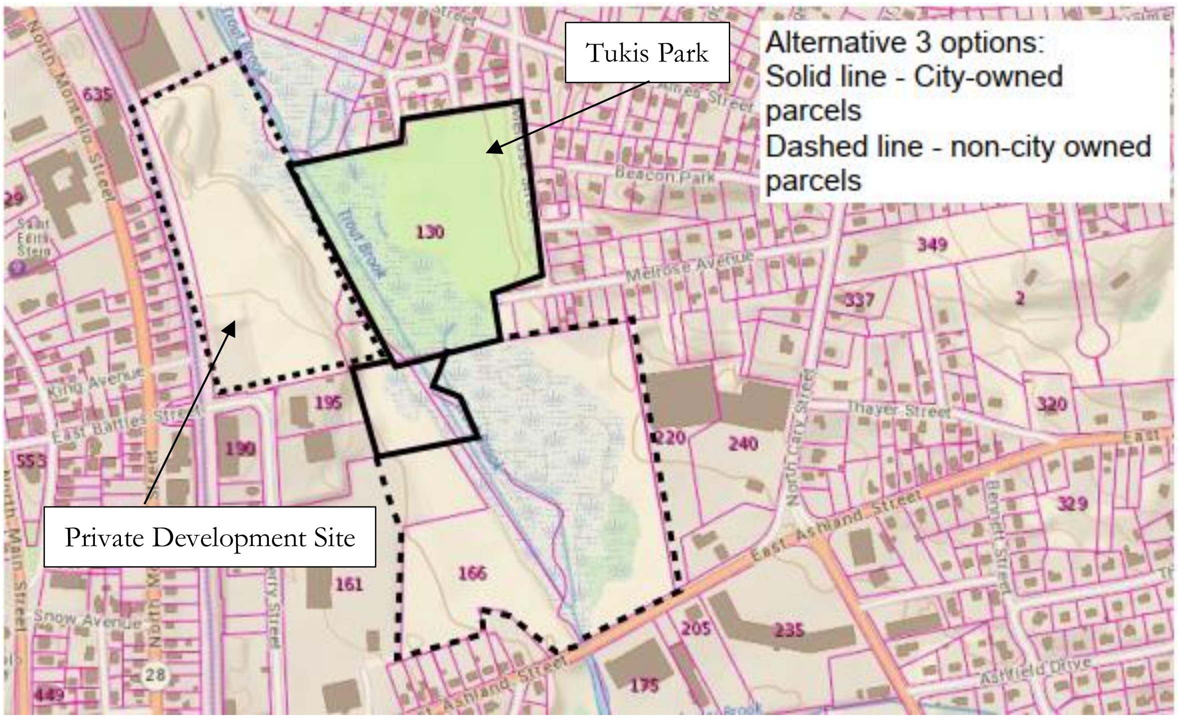


Figure 12: Alternative 3 Floodplain Restoration Parcels

Figure 13: Alternative 3 Floodplain Restoration Parcels

- Puffer Playground is also a potential floodplain restoration site owned by the City (Figure 13). There is also an undeveloped non-City owned parcel attached to Puffer Playground. This location is also where the Cary Brook tributary enters Trout Brook. However, restoration options are limited here since portions of this area are wetlands.

- There is a culvert under Court Street that extends under a parking lot and daylights approximately 135 feet downstream of the road crossing. Fuss & O'Neill evaluated the benefits that could be obtained by partially daylighting Trout Brook where the parking lot is located (189 Court Street). This would require the acquisition of this parcel and demolition of the parking lot and adjacent building by the City. The image below is a photo taken by Fuss & O'Neill Staff during the site visit that shows this area (Figure 14). In addition to this parcel, the City also owns a vacant parcel that connects to the parking lot area which will be included as part of the restoration plan (Figure 15).

Figure 14: Photograph of Culvert under Court Street (Area 5)

Figure 15: Alternative 3 Floodplain Restoration Parcels along Court Street

- The last location considered for Alternative 3 is Snow Park (Figure 16). This is a large City-owned park that could be renovated to provide additional flood storage during bigger storms while simultaneously serving its current community functions for recreation.
- In addition to these parcels considered for floodplain restoration, additional parcels known to have experienced repetitive flooding losses were considered for buyouts as an alternative means of protecting these areas from future flood risks.

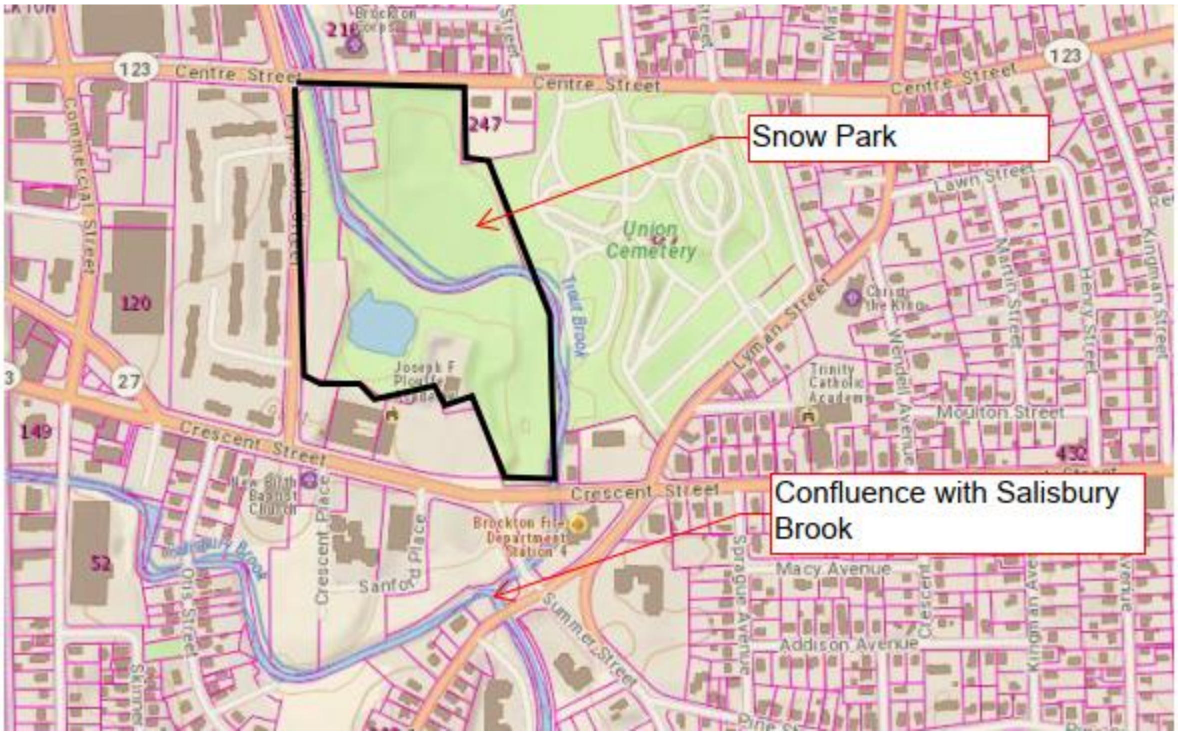


Figure 16: Potential Floodplain Restoration Area at Snow Park

4 Results and Recommended Alternative

Modeling of Alternative 1 showed that:

- Flooding was reduced by approximately 0.9 feet on average for the 100-year storm in and around the CSX railyard location.
- Areas that remain inundated (residential properties and roadways upstream of Court Street) are still under 2-3 feet of water.
- Flooding of structures within the immediate vicinity of the CSX railyard is eliminated for the 2-year storm, which is an improvement over existing conditions.
- There were no significant changes to flooding depths further upstream of Elliot Street or downstream of Court Street.
- Alterative 1 is not sufficient on its own to eliminate flooding from surrounding areas, but it would allow for redevelopment on the east and west side of the floodplain corridor through the CSX railyard since these areas are removed from the floodplain for all storm events analyzed (Figure 17).

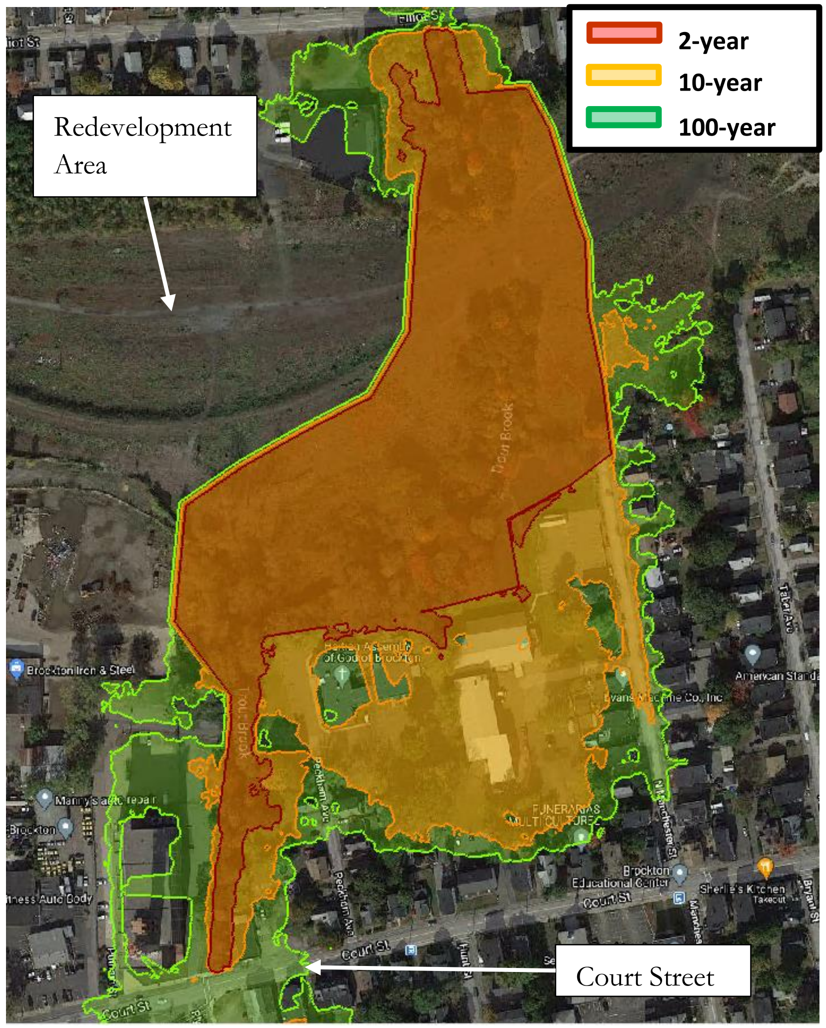


Figure 17: Modeling Results for Alternative 1 – grading within the central corridor of the CSX railyard

Alternative 2 that included expansion of the floodplain management area into the eastern side of the CSX railyard did not result in significant additional benefit compared to Alternative 1.

- Results showed that flooding was reduced by approximately 1.0 feet on average in and around the CSX railyard location for the 100-year storm.
- There were no significant changes to flooding depths upstream or downstream of this location.
- The costs associated with grading the Alternative 2 area are significant compared to the limited additional benefits it provides.

Analysis of floodplain restoration options within the parcels described as Alternative 3 ultimately showed that the hydraulic restrictions of the road crossings were shown to be a driving factor for flooding upstream and downstream of the CSX railyard; floodplain restoration alone was insufficient to significantly reduce flooding along the Trout Brook corridor. Modeling of additional floodplain storage at the parcels around Tukis Park (Figure 12), Puffer playground (Figure 13), and Snow Park (Figure 16) did not yield significant benefits and was not considered further.

Further investigation of the hydraulic restrictions showed that there is a low point in the terrain just south of the driveway crossing upstream of Court Street where water escapes the stream channel and flows over Peckham Avenue, inundating roads, houses, and businesses in this area (Figure 18). Modeling also indicates that Court Street is overtopped during the 100-year storm.

Based on the findings of the model, the recommended alternative incorporates floodplain restoration at the CSX railyard (Alternative 1) with the following additional elements to address the hydraulic restriction caused by limited culvert capacity at Court Street and prevent overtopping of adjacent roadways:

- Expand the existing 19.2-foot wide culvert under Court Street to a 50-foot wide span. To accommodate the grading necessary to increase the culvert to the proposed size, 188 Court Street (Parcel 163-015), which is currently assessed at approximately $150K and contains a commercial gutter business, would have to be acquired by the City (Figure 19). The upstream headwall on the Court Street culvert would be set to elevation 93.5, which is the elevation of the 100-year storm event under projected future conditions.
- Acquire 189 Court Street (Parcel 151-030; Figure 19) and daylight the buried section of Trout Brook via demolition of the existing parking lot.

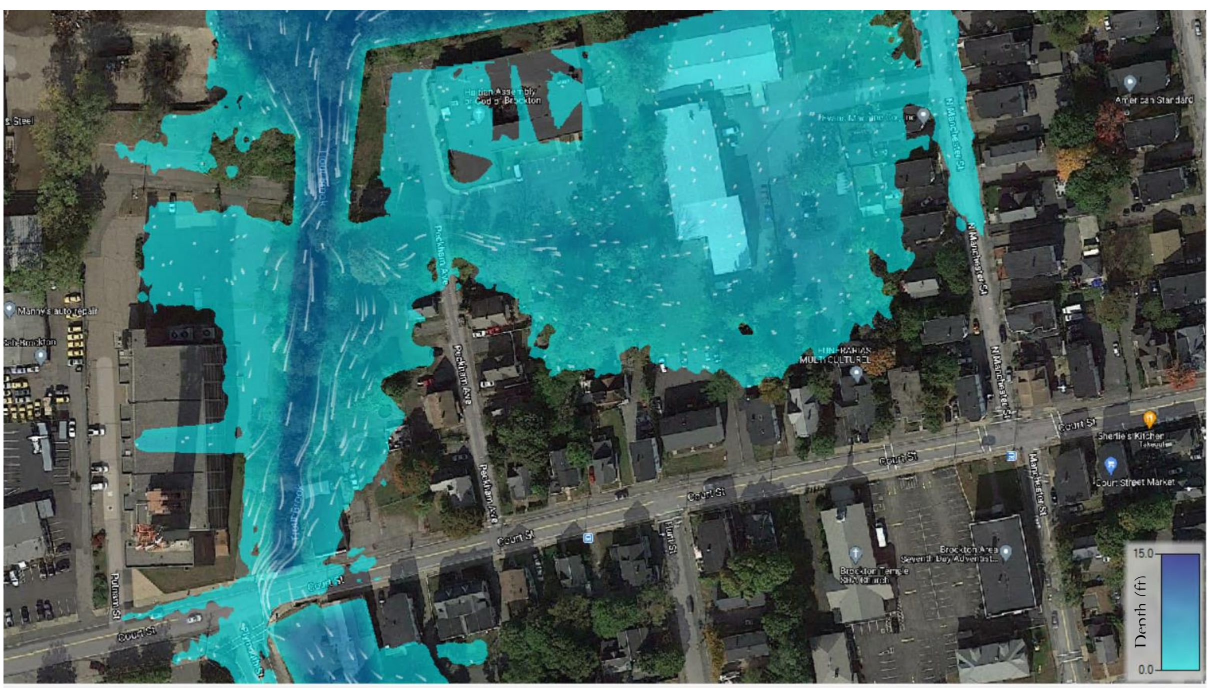


Figure 18: Flow Direction in CSX Area during the 100-year Storm

Figure 19: Parcel Acquisition Adjacent to Court Street Culvert

- Install a 2.5-3.5-foot tall walkable berm along both sides of Trout Brook running northward from Court Street. The upstream side of the berm would tie into the top elevation of the proposed grading from Alternative 1 (elevation 95.0). The berm would then taper to tie into elevation 93.5 at the intersection with Court Street.
- Raise the driveway crossing upstream of Court Street to elevation 94.5 (an approximately 0.8-foot raise) which will tie into the walkable berm and prevent overtopping of the crossing.
- Finally, to protect Plymouth Street from overtopping caused by the release of additional water once the capacity of the Court Street Culvert is increased, the sidewalk along Plymouth Street (tying into Court Street) must be raised between 0.5-1.5 feet to prevent overtopping from backwater effects during the projected 100-year storm.

Collectively, this recommended alternative will store water up to the projected 100-year storm and allow flow to pass through the widened Court Street culvert and downstream daylighted stream reach without inundating the buildings and roadways in this area or causing an increase in downstream flooding impacts. The recommended alternative which incorporates these elements along with the grading and floodplain restoration within the CSX railyard is shown in Figure 20.

The recommended alternative eliminates flooding of roads, business, and houses in the immediate vicinity of the CSX railyard and protects the proposed redevelopment site from future flooding for up to the 100-year storm. The areas that have been removed from the projected inundation area of the 100-year storm are as follows as shown on Figure 21:

- The buildings and roadways south of Alternative 1
- Court Street
- Plymouth Street
- Putnam Street
- Verizon building and parking lots lot east of Putnam Street
- Western section of CSX area where commercial buildings will be located

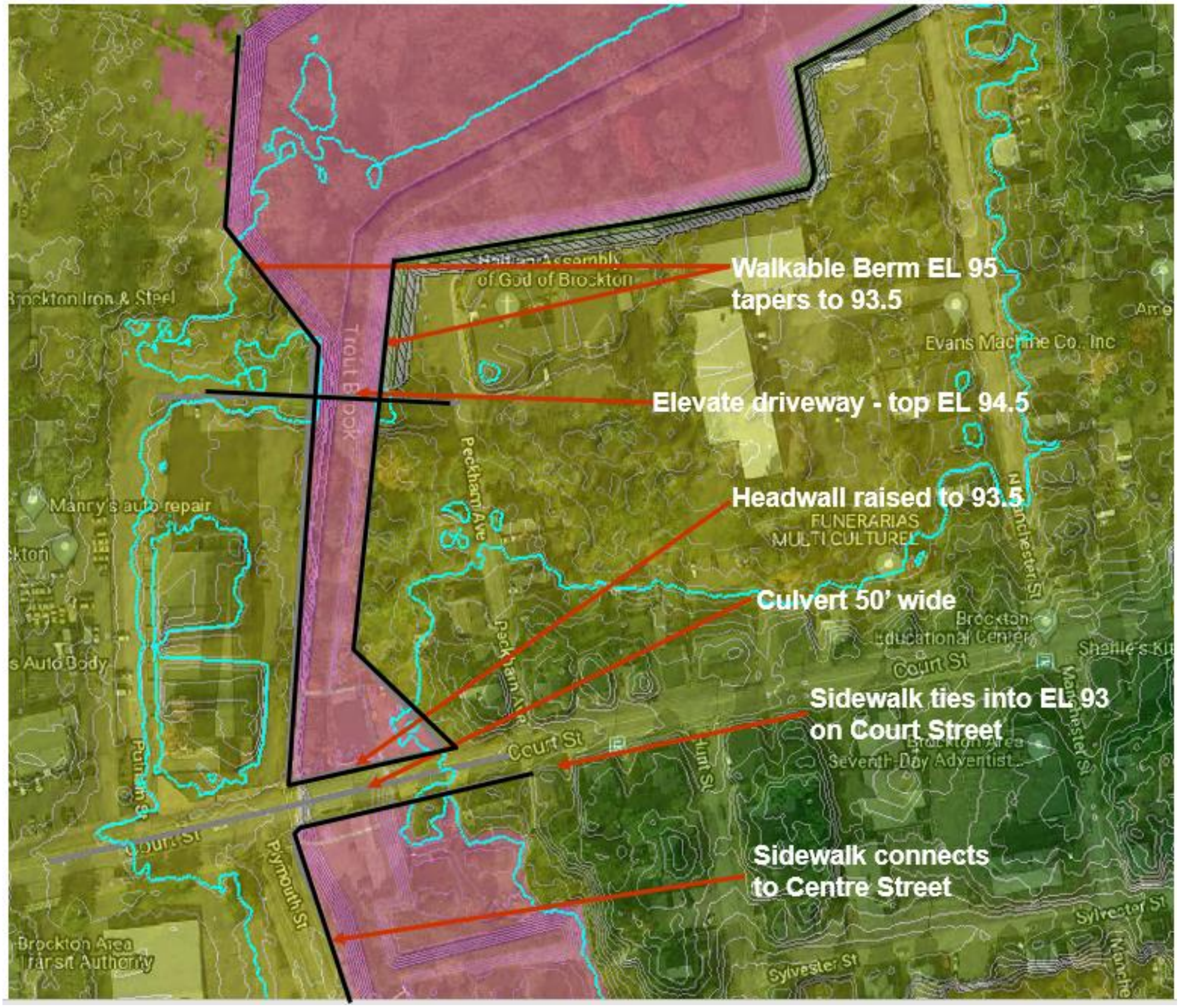


Figure 20: Recommended Alternative for Reduced Flooding along the Trout Brook Corridor

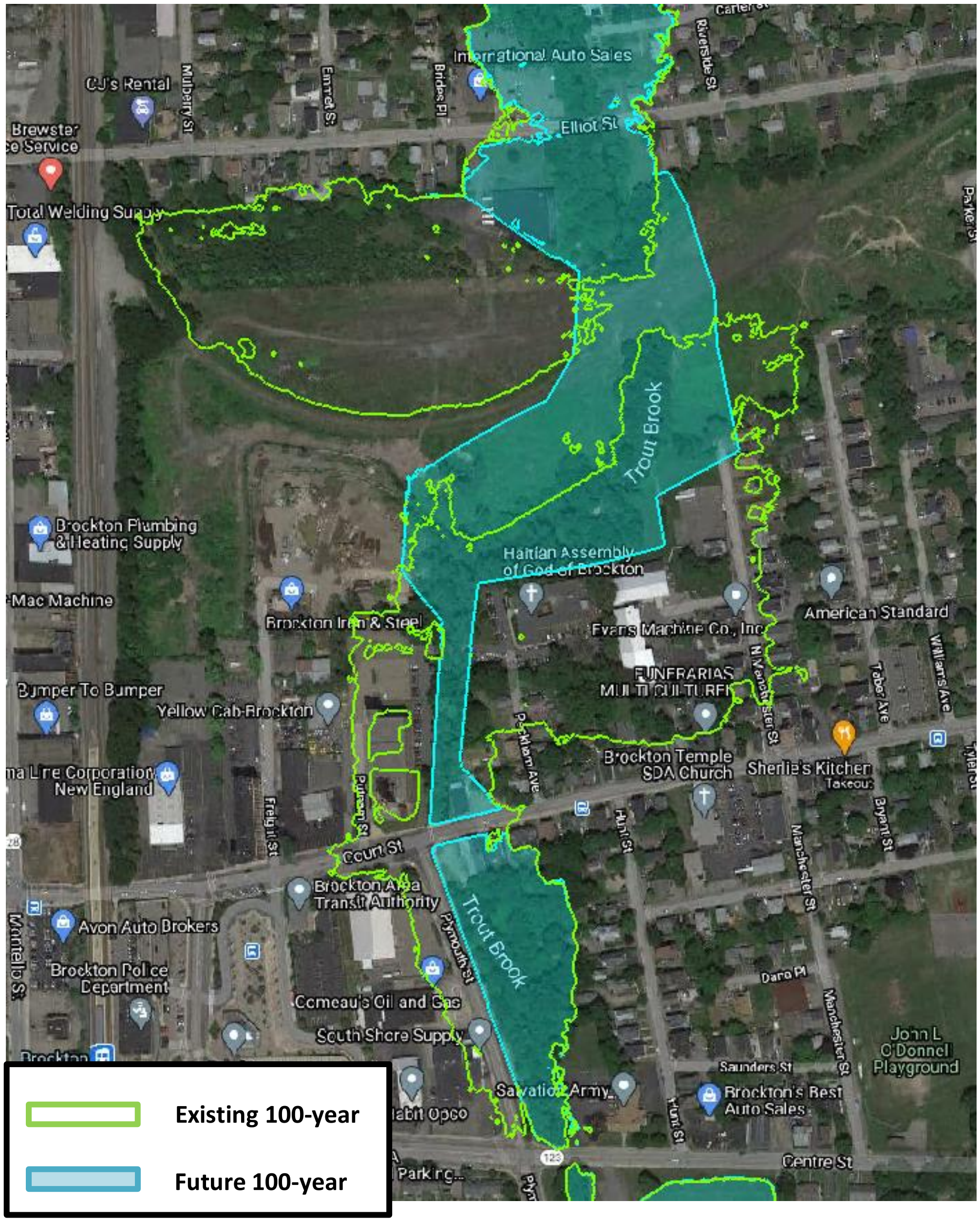


Figure 21: Extent of Restoration Benefits from Recommended Alternative

Graphics are presented in Appendix A that provide a snapshot of what the proposed restoration area in the CSX railyard could look like.

5 Benefit-Cost Analysis

An order-of-magnitude Benefit-Cost Analysis (BCA) was conducted for the recommended alternative. A BCA compares project costs with projected benefits, including avoided future flood damages to identify if the project is cost-effective—specifically, to identify if a project provides sufficient benefit/reduces future potential damages to a point that justifies the respective implementation costs. Projects with benefits that exceed the project cost are deemed cost-effective, have a Benefit-Cost Ratio (BCR) greater than 1.0 and can be funded by large grant programs such as FEMA BRIC (Building Resilient Communities and Infrastructure).

An order of magnitude opinion of project engineering and construction costs for the recommended alternative described above, based on the preliminary concept and a conservative estimate of necessary grading and excavation, yielded a project cost range of $7.8M to $16.7M. This number includes a 25% contingency, insurance and bonding, engineering design costs, traffic controls, and mobilization and demobilization in addition to the construction costs associated with the replacement culvert, excavation to create flood storage, and restoration of the floodplain corridor (see cost estimate details in Appendix B). Because of the unknowns at this early stage of the project, this range is calculated and presented as a -30% to +50% bracket, with the expectation that the ultimate project cost will most likely fall within this range.

In addition to these construction costs, there are significant land acquisition costs associated with the project. It is expected that the CSX railyard property (Parcel 163-192R) can be acquired for $7M. It is conservatively estimated that there would be approximately $2.4M in additional costs associated with property acquisition and associated legal costs for the City to acquire the following additional properties (see map in Appendix A): 188 and 189 Court Street, which are necessary to increase the capacity of the Court Street culvert (Parcels 163-015 and 151-030), Parcels 163-044R and 163-007, which abut the south edge of the CSX railyard and were included in the preliminary concept for flood storage, and four residential repetitive loss properties north of the project site which could not be otherwise removed from the 100-year flood zone, and for which buyout and relocation were deemed the best protection. There are also expected to be additional costs associated with easements for construction access and development of the berm—these are unknown at this time. While the acquisition costs are expensive, particularly for the CSX railyard, the City will be able to recoup a substantial portion of this money when the developable land is sold. A maximum of 8 of the 30 acres on the parcel are expected to be incorporated into the floodplain restoration project. Thus it would be expected that approximately $5.1M or more of the acquisition cost might be recovered through sale of the remaining, redevelopable land. For these reasons, the full acquisition cost would not necessarily be included in an official benefit cost analysis presented for funding.

This land acquisition likely brings the estimate of total costs to $17.2M to $26.1M. These costs are considered to be a conservative estimate based on existing information. A more detailed cost analysis should be conducted once detailed design is complete. In particular, this preliminary evaluation assumed maximum excavation within the limits of the floodplain restoration areas. More detailed analysis and grading will be completed during a future design phase which will allow for more accurate quantification of excavation costs. At present, excavation/earth moving makes up the largest single line item ($3.8M) in the construction budget. It is possible that this number could be reduced substantially during detailed design if grading is scaled back. For example, it may be possible to reduce excavation requirements while still achieving flood risk benefits. Also, the unit cost for excavation and soil disposal was selected from a range of possible costs offered by MassDOT. Actual unit costs will depend in part on the requirements for handling of excavated material; given the industrial history of the site, there may be substantial hazardous material disposal costs associated with excavation work. Future characterization of the levels of potential contamination on the site will allow disposal costs to be better understood. More accurate assessment on the part of the City will also allow for more precise quantification of acquisition costs.

FEMA methodology was then utilized as a basis to conduct an initial tally of benefits for this project. To estimate project benefits, the BCA focused primarily on the following:

- Damages to residential, commercial and industrial structures before and after implementation of the project; and
- Environmental improvements.

FEMA methodology applies a series of curves to estimate the value of damage to a structure during a flood event. Damages before and after project implementation are compared, and the difference between the two scenarios are considered project benefits. FEMA also considers benefits associated with environmental improvements. Projects where wetlands, riparian zones, green open space, etc. are restored or created have inherent benefits to flood mitigation. Therefore, FEMA has assigned a standard value to these improvements.

The initial BCA for the recommended alternative generated approximately $3.6M in benefits over the duration of its useful life (50 years per FEMA).

The total benefits were tallied based on the following key elements:

- Acquisition properties generated approximately $2.0M in benefits. Because these properties include Repetitive Loss Structures, it is expected that the majority of overall project benefits will be generated by these structures. Damages after project implementation are assumed to be $0 because the structures will be removed from the inundation area associated with the 100-year storm.
- The Verizon Building at 180 Court Street generated approximately $0.7M in benefits due to the fact that the western stairwell appears to overtop during the 50- and 100-year rainfall events, which results in stormwater getting into the basement; this flooding is prevented through implementation of the recommended alternative.
- Approximately $0.2M in benefits was tallied across an additional 15 structures along Court Street, North Manchester Street, and Peckham Avenue, each of which appears to have its lowest floor within 3 feet of the 100-year water surface elevation (note: for a residential structure, the lowest floor is usually the first floor and not the basement). Structures in which the lowest floor is higher than 3 feet above the elevation of the 100-year event typically have negligible benefits for purposes of this order-of-magnitude BCA.
- The remaining $0.7M in benefits were allocated for restoration of the floodplain, creation of green open space, and enhancing wetland functions in the area.

The FEMA BCA methodology allows additional sources of benefits that were not included in this analysis, including benefits for avoided road closures or loss of income. Considerable data is required to include these sources in the BCA (e.g., traffic counts, annual business revenue, etc.), and the respective data collection efforts were outside the scope of this analysis. Should the City ultimately wish to pursue a formal grant application with FEMA that requires calculation of a BCA, it is recommended that more thorough data collection and analyses be performed to accurately tally additional impacts and benefits to local businesses that may strengthen the benefit cost ratio. More precision in understanding prior or ongoing impacts actually experienced by businesses and properties due to flooding may also increase the benefits.

6 Conclusions and Future Work

The recommended nature-based improvements presented in this study will increase flood capacity by creating a floodable green space that provides additional flood storage capacity in the immediate vicinity of the CSX railyard as well as in upstream and downstream areas where known repetitive flooding losses have occurred. Areas of the CSX railyard which are currently within the floodplain will be removed from the inundation area of the 100-year storm under future climate conditions and protected for redevelopment. Downstream areas including significant commercial (Verizon, Evans Machine Co.), institutional (Haitian Assembly of God of Brockton), and residential properties will also be removed from the projected future 100-year inundation area. The flood resiliency project will also allow for creation of a walkable green corridor to create continuous public green space along the brook as a public amenity, providing the community with both a nature-based solution to safely store water during flood events and enhanced connectivity and walkable access to recreation opportunities within the surrounding neighborhoods.

The preliminary benefit-cost calculation presented here for this concept yields a cost benefit ratio of approximately 0.3 (excluding $5.1M in acquisition costs from the CSX property that could be recouped through sale of the developable land). However, this initial estimate is doubly conservative: it both potentially overestimates costs and underestimates benefits. There is significant room to adjust this ratio during a future design phase, both through increased precision of information and through adjustments to the design concept. In addition, it should be noted that because this cost-benefit calculation was modeled off of the FEMA methodology, its focus is on hazard reduction. Additional benefits would accrue to the City from the project, such as the ability to redevelop the CSX railyard without threat of future flooding, the value of jobs associated with new commercial development in these areas, tax revenues generated by both commercial and residential properties in the redevelopment area, increased connectivity between neighborhoods and parks in the area surrounding Trout Brook, and improved aesthetics and amenities in an underserved neighborhood. While not tallied as part of this analysis, these benefits have significant value for Brockton and may provide the necessary balance to make the project worthwhile. If the entire project does not qualify for FEMA funding based on the final benefit-cost ratio, a portion of the project can still be funded through FEMA, with other state or federal programs used to fund additional portions of the project. These funding sources might include brownfields redevelopment programs and parks programs to fund acquisitions that contribute to the trail network.

The technical data in this report serves as proof of concept that significant flood reductions along Trout Brook can be obtained through nature-based solutions. This should be considered a jumping off point from which to further define a design and project that meets the City's needs and can be successfully funded and implemented. We recommend as a next step that the City proceed with a preliminary design phase to better assess the scale of excavation required and tailor the project to maximize the value of the benefits (e.g., some above ground flooding may be deemed tolerable in certain areas) and better characterize soils and contamination. Further modeling should also consider additional options for managing flooding north of Elliot Street, for example, by extending the recommended berm further northward to determine whether additional flood protection can be gained in those areas.

Appendix A

Concept Renderings

CONTEXT PLAN

FUSS & O'NEILL

SCALE: 1" = 400'

0' 200' 400' 600' 800'

N

TROUT BROOK FLOODPLAIN RESTORATION

BROCKTON, MA

June 2021

PARCEL ACQUISITION PLAN

FUSS & O'NEILL

SCALE: 1" = 400'

0' 200' 400' 600' 800'

N

TROUT BROOK FLOODPLAIN RESTORATION

BROCKTON, MA

June 2021

CONCEPTUAL SITE PLAN

FUSS & O'NEILL

SCALE: 1" = 150'

0' 75' 150' 225' 300'

N

TROUT BROOK FLOODPLAIN RESTORATION

BROCKTON, MA

June 2021

PROPOSED BOARDWALK THROUGH CSX RESTORATION AREA

VIEW SOUTH TOWARD COURT STREET

Appendix B

Preliminary Opinions of Cost

FUSS & O'NEILL, INC.

1550 Main Street, Suite 400
Springfield, MA 01103

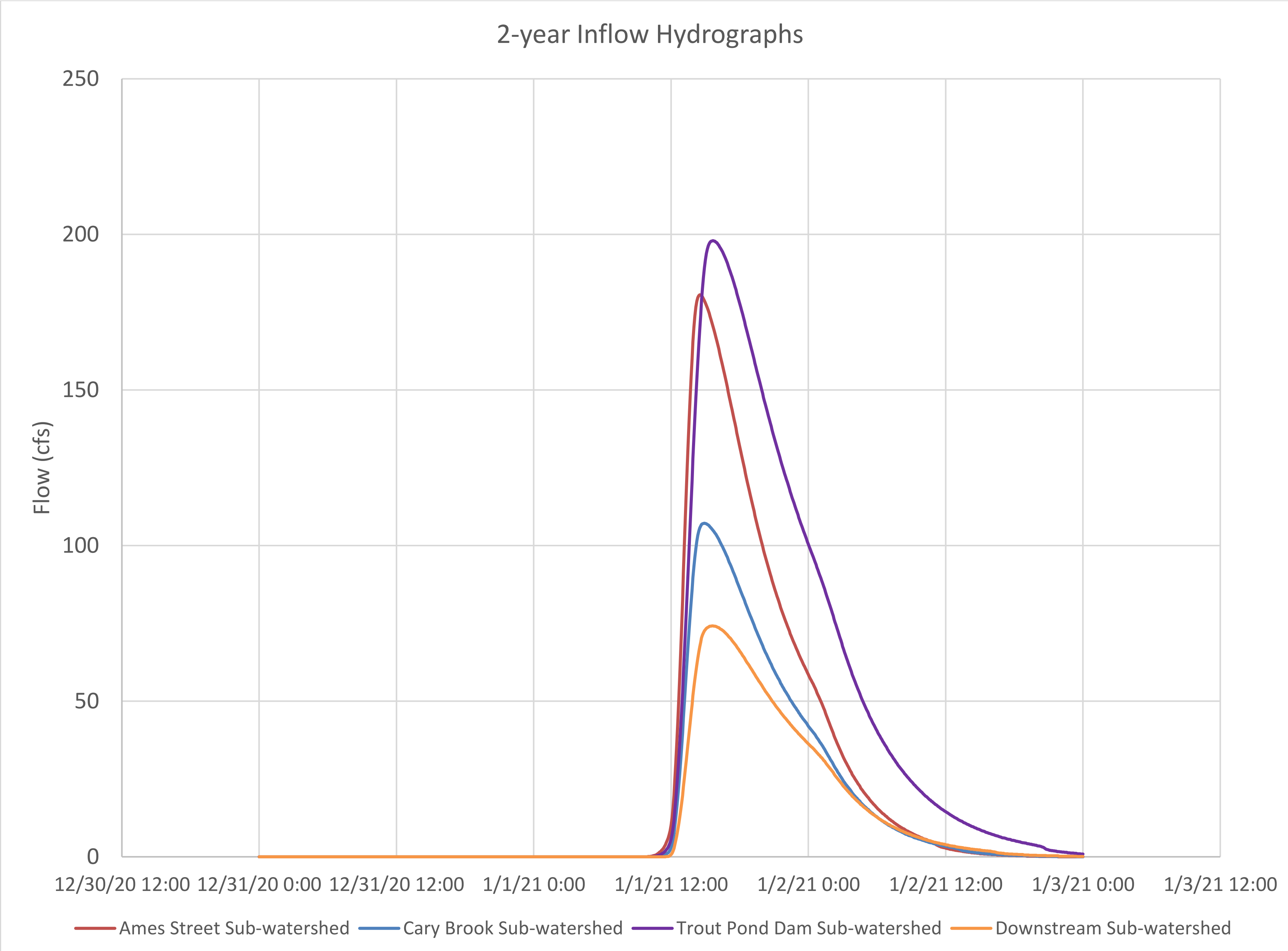
ORDER OF MAGNITUDE OPINION OF COST	DATE PREPARED : 2 06/11/21	SHEET 1 OF 1
PROJECT : **Trout Brook Floodplain Restoration**	BASIS : 2020-2021 Mass Highway Weighted Average Bid Prices, 2019 ConnDOT Cost Estimating Guidelines, 2020-21 RIDOT Weighted Average Unit Prices, latest RS Means, and Previous Construction Projects.	
LOCATION : **Brockton, Massachusetts**		
DESCRIPTION **Order of Magnitude Opinion of Cost**		
DRAWING NO. **Concept Sketches**	ESTIMATOR : DRN	CHECKED BY :

Since Fuss & O'Neill has no control over the cost of labor, materials, equipment or services furnished by others, or over the Contractor(s)' methods of determining prices, or over competitive bidding or market conditions, Fuss & O'Neill's opinion of probable Total Project Costs and Construction Cost are made on the basis of Fuss & O'Neill's experience and qualifications and represent Fuss & O'Neill's best judgment as an experienced and qualified professional engineer, familiar with the construction industry; but Fuss & O'Neill cannot and does not guarantee that proposals, bids or actual Total Project or Construction Costs will not vary from opinions of probable cost prepared by Fuss & O'Neill. If prior to the bidding or negotiating Phase the Owner wishes greater assurance as to Total Project or Construction Costs, the Owner shall employ an independent cost estimator.

ITEM NO.	ITEM DESCRIPTION	UNIT MEAS.	NO. UNITS	PER UNIT	TOTAL COST
1	**Site Preparation**				
	Water Control	LS	1	$200,000	$200,000
	Erosion and Sediment Controls	LS	1	$60,000	$60,000
	Site Preparation Subtotal				$260,000
2	**Site Demoltiton**				
	Clearing and Grubbing	AC	6.1	$36,000	$220,000
	Demolition of Existing Culverts/Surrounding Material to Accommodate New Channel	CY	550	$1,350	$742,500
	Demolition of Existing Building	LS	1	$50,000	$50,000
	Remove and Dispose Sidewalks	CY	100	$150	$15,000
	Full Depth Pavement Sawcut	FT	100	$3	$300
	Remove and Dispose Pavement	SY	2,600	$20	$52,000
	Site Demolition Subtotal				$1,079,800
3	**Civil Construction**				
	Earth Excavation	CY	110,000	$35	$3,850,000
	Fine Grading	SY	2,600	$6	$15,600
	Gravel Borrow for Road Raising /Sidewalks	CY	1,200	$45	$54,000
	Repurposed Excavated Material for Earthen Berm	CY	750	$30	$22,500
	Bituminous Concrete Pavement	Ton	525	$140	$73,500
	Concrete Sidewalk	SY	900	$65	$58,500
	Civil Construction Subtotal				$4,074,100
	Culvert Replacement				
	Court Street Replacement Culvert	SF	2,750	$420	$1,155,000
	Culvert Replacement Subtotal				$1,155,000
	Site Restoration				
	Loam and Seed	SY	29600	$10	$296,000
	Site Restoration Subtotal				$296,000
	Constrution Subtotal				**$6,864,900**
	Miscellaneous Lump Sum Items				
	Mobilization & Demobilization	LS	1	$447,000	$447,000
	Access and Staging Area Preparation, Maintenance and Restoration	LS	1	$50,000	$50,000
	Traffic Control	LS	1	$30,000	$30,000
	Construction Survey Layout and As-Built Mapping	LS	1	$20,000	$20,000
	Field and Laboratory Testing	LS	1	$25,000	$25,000
	Insurance and Bonds	LS	1	$138,000	$138,000
	Engineering	LS	1	$1,373,000	$1,373,000
	CONSTRUCTION ADMINISTRATION SUBTOTAL				**$2,083,000**
	OVERALL SUBTOTAL				**$8,947,900**
	CONTINGENCY (25%)				$2,237,000
	OVERALL TOTAL INCLUDING CONTINGENCY				**$11,185,000**
	SUBTOTAL -30% TO +50% (ROUNDED TO NEAREST $1,000)		**$7,830,000**	**TO**	**$16,778,000**

Appendix C

HEC-HMS Inflow Hydrographs


2-year Inflow Hydrographs
Flow (cfs)
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200
150
100
50
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1/1/21 12:00
1/2/21 0:00
1/2/21 12:00
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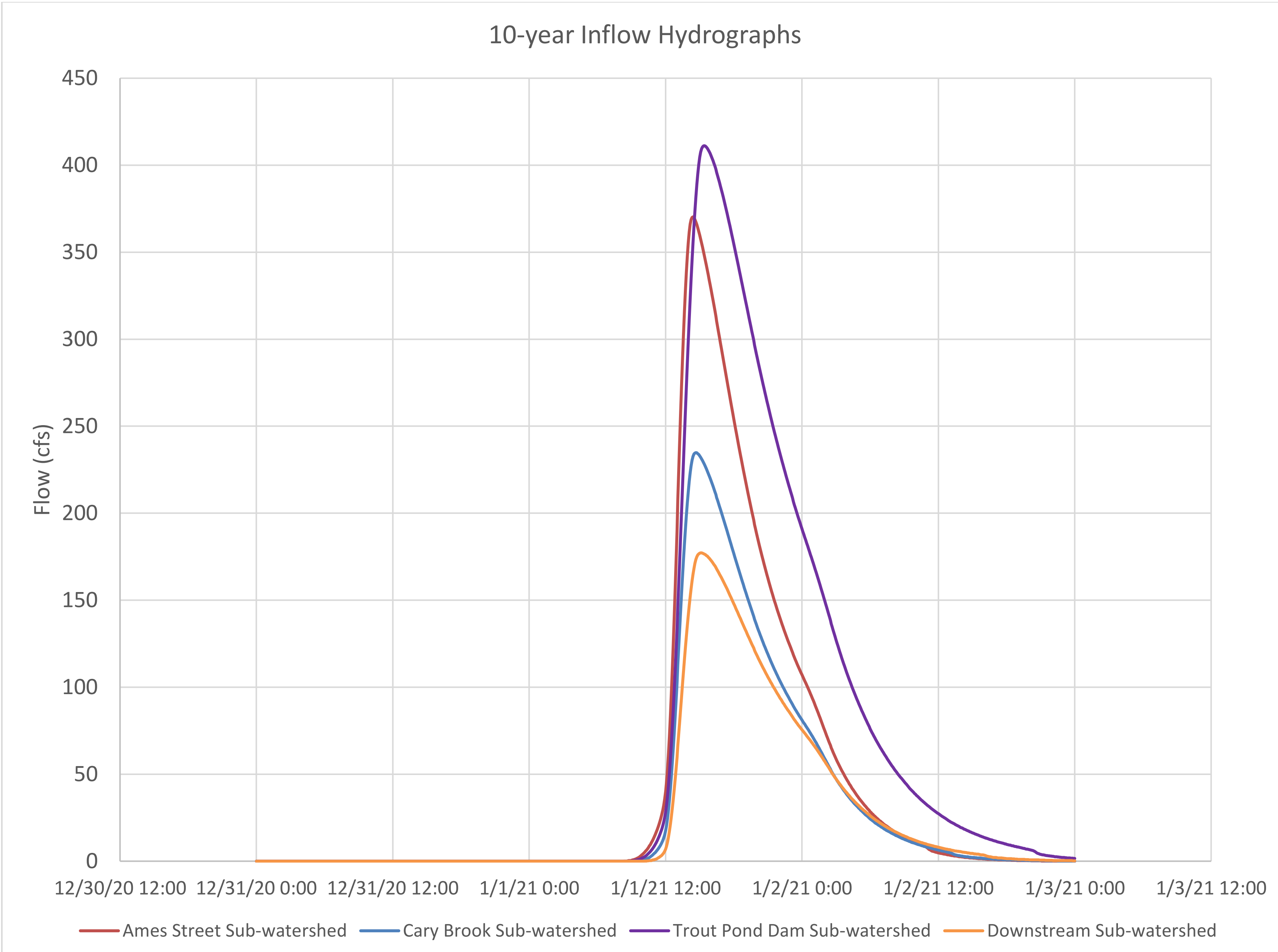
1/3/21 12:00
Ames Street Sub-watershed
Cary Brook Sub-watershed
Trout Pond Dam Sub-watershed
Downstream Sub-watershed


10-year Inflow Hydrographs
Flow (cfs)
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300
250
200
150
100
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1/2/21 12:00
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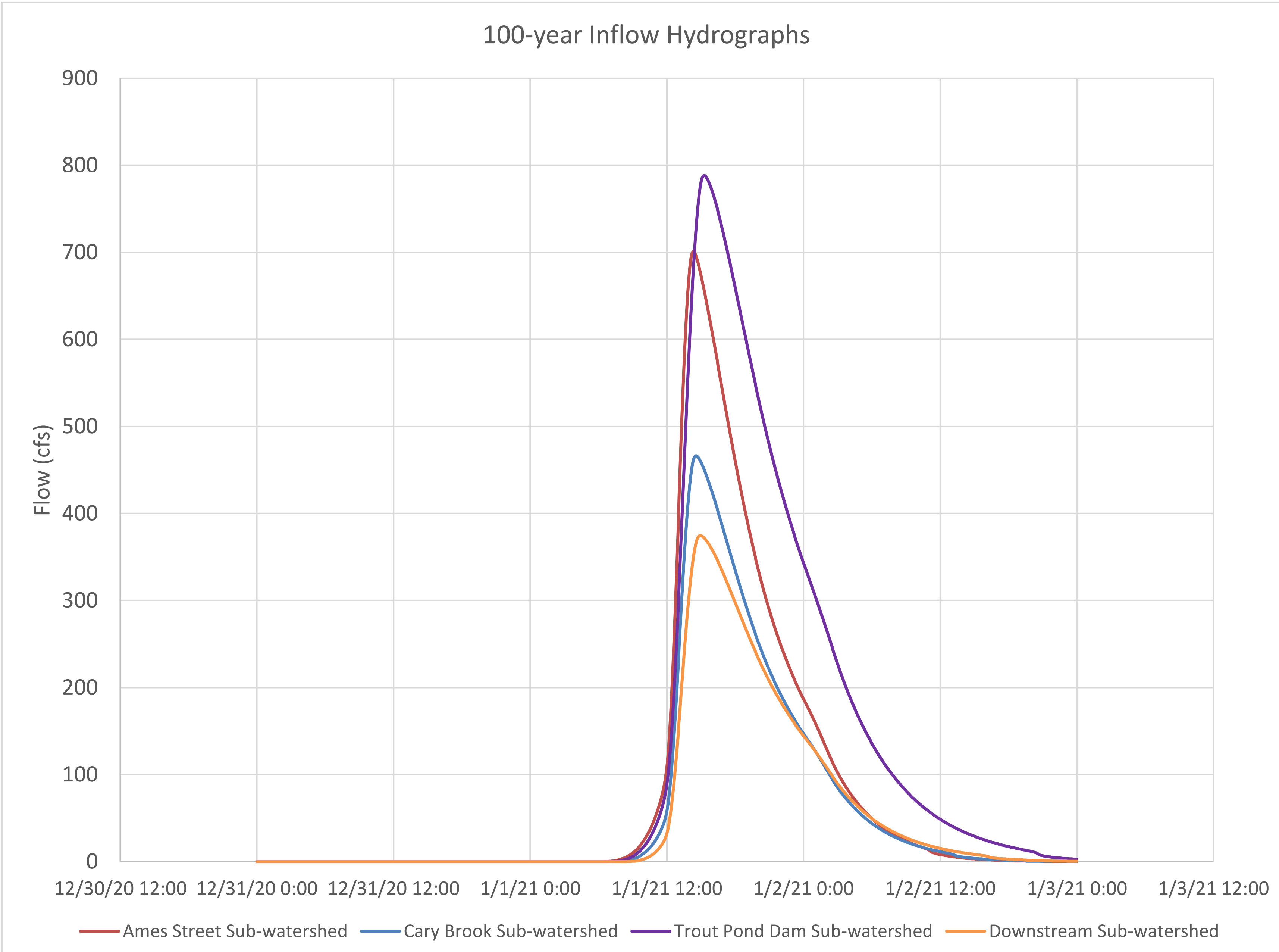
1/3/21 12:00
Ames Street Sub-watershed
Cary Brook Sub-watershed
Trout Pond Dam Sub-watershed
Downstream Sub-watershed


100-year Inflow Hydrographs
Flow (cfs)
900
800
700
600
500
400
300
200
100
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1/2/21 0:00
1/2/21 12:00
1/3/21 0:00
1/3/21 12:00
Ames Street Sub-watershed
Cary Brook Sub-watershed
Trout Pond Dam Sub-watershed
Downstream Sub-watershed

Financial assistance was provided by the Executive Office of Energy & Environmental Affairs (EEA) under the FY19 Municipal Vulnerability Preparedness (MVP) Grant Program. The MVP Action Grant offers financial resources to municipalities that are seeking to advance priority climate adaptation actions to address climate change impacts resulting from extreme weather, sea level rise, inland and coastal flooding, severe heat, and other climate impacts.

Consultant Team

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Dean Audet, PE; Nina Marelli

Document photos and graphics produced by Fuss & O'Neill unless otherwise noted.