Nature-Based Solutions for Flood Resiliency
Salisbury Brook & Salisbury Plain River

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 conduct a study that would develop an accurate understanding of risks to infrastructure, environment, and residents resulting from flooding events in the City and to identify solutions to address those risks and increase flood resiliency along Salisbury Brook and the Salisbury Plain River. This report documents the process and findings of that study, and presents recommendations for nature-based approaches that mimic and/or work with natural systems to increase flood storage capacity, decrease flooding risk, and proactively increase the City's resilience to climate change impacts.

Project Background and Overview

The City has been experiencing an increasing frequency of storms causing flooding problems in neighborhoods and roads. Intense storms occurring throughout the year are producing high volumes of rain, causing rivers and streams to overflow their banks, placing significant pressure on dams and culverts and overwhelming the stormwater infrastructure system. Flooding frequently has City-wide impacts, including road closures at susceptible locations, such as Crescent Street and the Kmart Plaza on Main Street. Extreme precipitation and flooding events are expected to become more frequent due to climate change impacts.

Because of a high degree of impervious surfaces in the City, even moderate volumes of stormwater in Brockton can result in flooded buildings and infrastructure. In 2010 rescuers had to pull residents out of flooded homes from a boat, and certain neighborhoods are known to be particularly susceptible to flooding and related power outages. Along Belmont Avenue, four homes have already been bought-out by the City and demolished due to having experienced repetitive losses from flooding

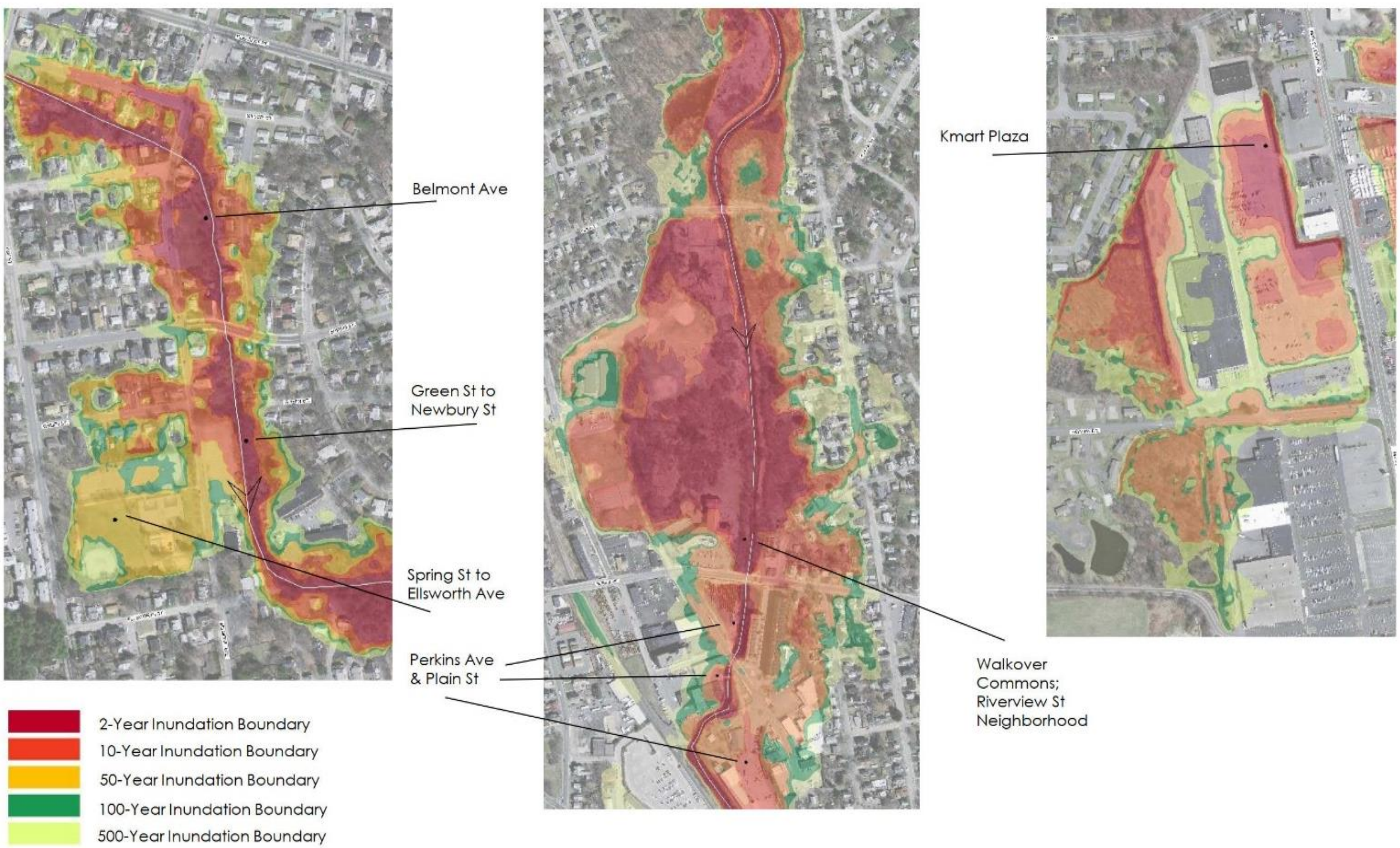
In order to develop a plan to address these flooding issues on a City-wide scale, rather than on a site-by-site basis, the City partnered with Fuss & O'Neill to secure funding through the MVP Action Grant program to develop an integrated all-waters approach to increase flood resiliency City-wide. From the start of this project, the City has been very cognizant of its downstream neighbors, recognizing that moving water through the City faster might alleviate some flooding concerns, but would only cause greater impacts for downstream communities. The approaches highlighted here focus on detaining and infiltrating water higher up in the watershed to limit downstream flooding impacts. The project was designed to assess the viability of using nature-based solutions such as restoration of wetlands and floodplain or implementation of green infrastructure to address both riverine flooding and stormwater drainage-driven flooding, and to prioritize future projects to increase flood storage capacity and mitigate flooding risk.

Example Inundation Mapping within River Corridor

Flood Prone Areas

Fuss & O'Neill conducted hydraulic and hydrologic modeling of the Salisbury Brook and Salisbury Plain River corridor, which bisects the City from north to south. This type of modeling allows us to predict and map the limits of inundation—that is, how far flood waters will spread—during different size storm events. The results of the analyses identified areas most susceptible to frequent flooding, including those shown here. Inundation mapping for the entire river corridor is available in the full report.

Modeling also revealed that several bridges throughout the river system overtop during the 10-year flood event, including Prospect Street, Belmont Avenue, North Arlington Street/Newbury Street, Pine Avenue, and Perkins Avenue. These are considered to be the bridges most susceptible to flooding during significant rainfall events.



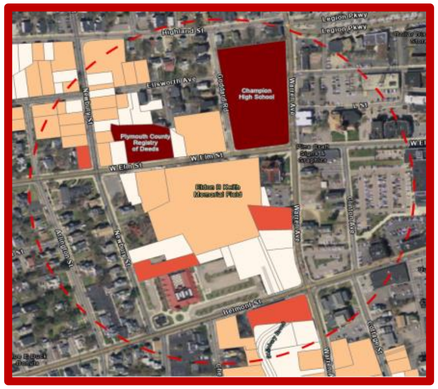
Projected Climate Impacts

Climate change is impacting rainfall patterns, making heavier and more intense rainfall events more frequent throughout the northeast. Increasing intensity and frequency of larger storm events will contribute to a worsening of flooding conditions along the Salisbury Brook/Salisbury Plain River system. To account for predicted future conditions, the hydraulic model built for this project applies a precipitation magnification factor that models future precipitation events as approximately 20% larger than current storms. (This magnification factor is consistent with climate projections at the regional and local scales.) By the year 2040, projections indicate that at various points in the river system, the 2-year flood will result in flood elevation levels that vary from 1 inch to 16 inches higher than currently experienced during the 2-year flood, while the 100-year flood in 2040 will result in increased flood elevation levels that range from 1 inch to 31 inches higher than currently experienced during the 100-year flood.

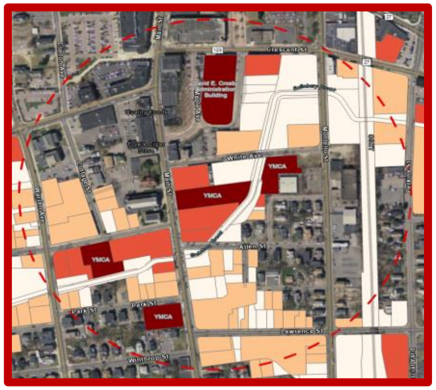
Risk Assessment and Prioritization

A risk assessment and prioritization tool was developed specifically for the City of Brockton that utilizes a weighted scoring method to prioritize property/parcels and road and bridge infrastructure located within the mapped inundation areas. Parcels within the floodplains of Salisbury Brook and the Salisbury Plain River were categorized and scored based on the following factors:

- ‘criticality’, where more critical facilities are those where even a small chance of flooding poses a significant threat to public health and safety (e.g. hospitals, police stations)
- potential impacts to economic development and jobs
- value in providing housing for City residents
- value of potential direct financial damages in a flooding event
- geographic extent of impacts for roadways



The prioritization process was used to identify individual properties with high risk scores, as well as to identify locations where risk clusters. Such clusters help to highlight areas of residential or otherwise non-critical use which may not score high individually, but which represent a risk ‘hotspot’ within the City.



Darker shades indicate locations with higher assessed risk scores.

Nature-Based Solutions for Flood Storage

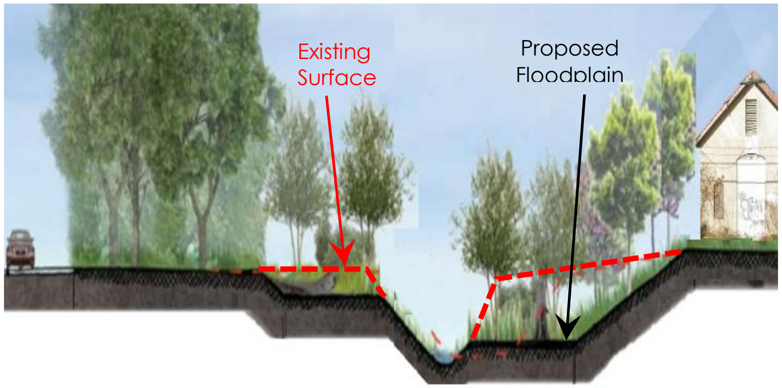
Nature-based solutions focus on restoring and/or enhancing natural habitat and flood storage functions of pond or floodplain areas to increase flood storage and lower water flood elevations. Restoration techniques include excavation to increase floodplain storage, widening the river channel in areas where development has resulted in encroachment into the river's natural floodplain, and daylighting buried stream channels.

City-owned and undeveloped parcels were given first consideration as sites for nature-based solutions; acquisitions and buy-outs of developed property were also considered, though these options are typically more costly.

Assessment included an evaluation of three types of alternatives:

- Excavation and ecological enhancement of Ellis Brett Pond or Cross Pond
- Floodplain restoration at undeveloped parcels
- Buy-out/relocation and floodplain restoration at developed sites

Order of magnitude cost/benefit analyses were conducted for each alternative to aid in prioritization of recommended projects. Three prospective solutions emerged from the analysis as among the most beneficial and cost-effective options.



Typical Floodplain Restoration Section (modified from VDOT, 2018)

1) Installation of a spillway gate and implementation of water level management strategy at Ellis Brett Pond

A remotely-controlled bottom-hinged crest gate would allow the City to better take advantage of existing flood storage available in Ellis Brett Pond. With a gate installed, water levels could be lowered before large storm events, then the gate could be raised to allow for detention of runoff for later release to the river in a controlled manner.

- Best independent alternative
- Benefits throughout river system
- 6 inch to 1 foot+ flooding reductions throughout upper reaches
- Primary benefits for 2-year and 10-year events
- Estimated cost: $400K to $900K (excludes operation/maintenance)

Installation of Spillway Gate at Ellis Brett Pond: Modeled Change in Water Surface Elevation for Each Storm Event (feet). Reductions of 0.2 feet or greater shown in blue.

Location in River System	2-Year	10-Year	50-Year	100-Year
Elmwood Ave to Pleasant St	-1.0	-0.7	-0.0	0.0
Pleasant St to Moraine St Conduit	-1.1	-0.9	-0.1	0.0
Moraine St Conduit to Ash St	-0.8	-0.7	-0.3	0.0
Ash St to Belmont Ave	-0.8	-0.4	-0.1	0.0
Belmont Ave to Carleton St	-0.6	-0.3	-0.1	0.0
Carleton St to N. Arlington Culvert	-0.9	-0.5	-0.1	0.0
Belmont St to Allen St	-0.6	-0.3	0.0	0.0
Allen St to White Ave	-0.4	-0.1	-0.1	0.0
White Ave to Railroad Bridge	-0.5	-0.2	-0.1	0.0
Railroad Bridge to Otis St	-0.4	-0.1	-0.1	0.0
Otis St to Grove St	-0.3	-0.2	-0.1	0.0
Pine Ave to Perkins Ave	-0.4	-0.1	-0.1	0.0
Perkins Ave to Plain St	-0.4	-0.2	-0.1	0.0
Plain Street to Sargent's Way	-0.2	-0.1	0.0	0.0
Sargent's Way to K-Mart Plaza	-0.2	-0.1	0.0	0.0

2) Excavation and ecological enhancement of Ellis Brett Pond

Ellis Brett Pond currently has a normal impoundment surface area of approximately 1.6 acres and normally holds approximately 13,000 cubic yards of water. The pond is impounded by a dam and is generally maintained under dry conditions with minimal flow controls (weir boards) applied to the dam's primary spillway. Excavation and wetland restoration/enhancement is proposed for up to a nine acre area, primarily to the north of the existing impoundment, to increase the available storage area below the typical water surface elevation.

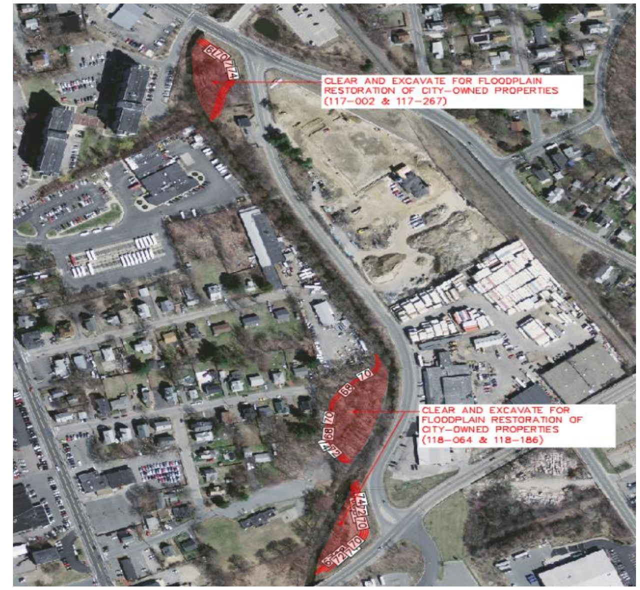
- Up to six inch reduction in flood elevation for 2-year through 100-year events as an independent alternative
- Benefits extend from impoundment to Otis Street
- Potential permitting challenges
- Estimated cost: $2.5M to $5M

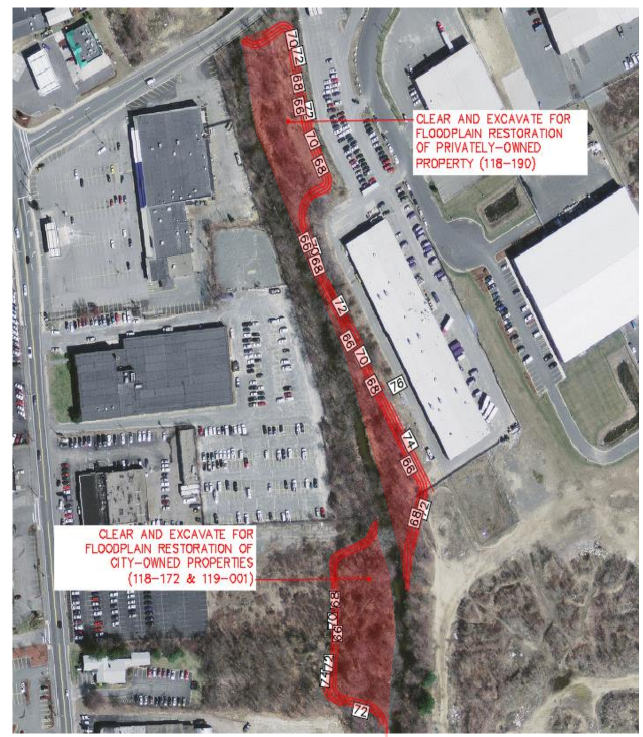
Proposed Ellis Brett Pond Excavation Limits

3) Floodplain restoration of undeveloped parcels near Sargent's Way

Excavation is proposed at three undeveloped City-owned parcels between Plain Street and Sargent's Way to create an additional 18,300 cubic yards of floodplain storage. An additional 22,500 cubic yards of flood storage is propose to be created through excavation at three undeveloped areas within privately-owned parcels immediately downstream of Sargent's Way along a constricted section of the river channel.

- 7 inch to 9 inch reductions in flood elevation for the 2-year through 100-year events
- Impacts limited to Pine Street and downstream
- Increases flood elevation reductions at the south end of the City relative to Ellis Brett Pond alternatives
- Estimated cost $2.5M to $4.8M





Potential Floodplain Restoration areas between Plain Street and Sargent's Way (top) and downstream of Sargent's Way (bottom)

Recommended Approach

Our recommended approach is to implement a nature-based approach that includes both excavation of Ellis Brett Pond to increase flood storage volume and the installation of a gate structure at Ellis Brett Pond, as well as restoration of floodplain at the three undeveloped parcels in the vicinity of Sargent's Way. This alternative combines two key approaches:

- Utilizing the Ellis Brett Pond Dam, to hold additional water during storm events and control its release.
- Applying floodplain restoration approaches that excavate key properties along the river corridor to create additional floodplain storage where Salisbury Plain River is currently restricted by channelized banks and/or development within the floodplain.

Together, these approaches yield additional flood storage at key points in the river system, resulting in up to 18 inch reductions in flood elevations during more frequent flood events. Significant benefits are seen throughout the length of the river during the 2-year and 10-year floods, and several bridges are protected from overtopping during the 10-year flood. This alternative also provides flood reduction benefits throughout the river system for the 50-year flood, including protection of the White Avenue Bridge crossing from overtopping during that event. The downstream floodplain restoration work provides additional protection for commercial properties at the south end of the City, adding significant additional benefit between Pine Ave. and Sargent's Way for the 10-yr through 500-yr storm events relative to inclusion of the Ellis Brett components alone.

This cost-effective, high-impact solution can reduce the risk of flooding City-wide, with up to 18 inch reductions in flood elevations during more frequent flood events.

The order of magnitude costs for the combined approach is estimated at $7 million, with a likely cost range between $5M and $10.5M. By prioritizing this cost-effective, high-impact solution, the City can reduce the risk of flooding City-wide. This strategy is much more efficient than implementing site-by-site protections for at-risk buildings or infrastructure.

Despite these benefits, the preferred alternative does not address all known flooding areas. Additional flood protection measures will be needed to round out a comprehensive resiliency strategy for the City.

Green infrastructure applications for on-site stormwater management should be explored throughout the City, including during any future redevelopment of the K-Mart Plaza or Westgate Mall properties. Modeling revealed that because of the Westgate Mall's relatively small size relative to the watershed, coupled with the high degree of impervious cover throughout the watershed, installing green infrastructure at the mall would have little impact on flooding at a City-wide scale. However, wider implementation of green infrastructure throughout the watershed and throughout the City could certainly have important impacts on downstream flooding by infiltrating water in place and reducing peak flows. Such practices also have significant value improving water quality.

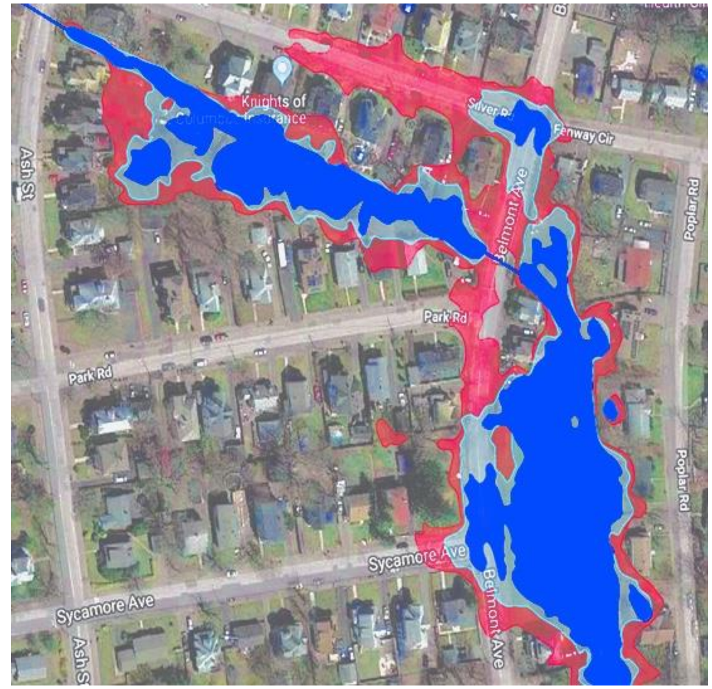
The results of our hydraulic and hydrologic modeling also indicate the importance of attenuating floodwaters upstream in the City's other watersheds, before they contribute to the flows in the Salisbury Plain River. Additional study and modeling should also focus on developing appropriate, parallel nature-based solutions for Trout Brook and other areas of the City in order to develop a comprehensive approach to nature-based flood protections.

Over time, proposed additional measures may include property buy-outs to facilitate planned retreat, and relocating land uses at flood-prone properties to more protected areas of the City. Done strategically, these efforts can be part of a planned redevelopment strategy that simultaneously protects residents and established businesses from climate impacts, creates green space in the City, and opens up **opportunities for mixed-use densification to invigorate the City's economic base.**

Modeled Flood Reductions for the Recommended Approach

(Ellis Brett Pond Spillway Gate and Excavation, downstream floodplain restoration)

	Modeled Change in Water Surface Elevation for Each Storm Event (feet)				
Location in River System	2-Year	10-Year	50-Year	100-Year	500-Year
Elmwood Ave to Prospect St	-1.3	-0.9	-0.1	0.0	0.0
Prospect St to Pleasant St	-1.4	-1.0	-0.1	0.0	0.0
Pleasant St to Moraine St Conduit	-1.5	-1.4	-0.3	-0.2	-0.1
Moraine St Conduit to Ash St	-1.3	-1.0	-0.8	-0.6	-0.1
Ash St to Belmont Ave	-1.3	-0.7	-0.3	-0.3	-0.1
Belmont Ave to Carleton St	-1.1	-0.9	-0.3	-0.1	-0.1
Carleton St to N. Arlington Culvert	-1.1	-1.1	-0.3	0.0	-0.1
Belmont St to Warren Ave	-0.8	-0.5	-0.2	-0.1	-0.1
Warren Ave to Allen St	-0.8	-0.4	-0.2	-0.1	0.0
Allen St to White Ave	-0.5	-0.2	-0.7	-0.1	0.0
White Ave to Railroad Bridge	-0.7	-0.3	-0.8	-0.2	0.0
Railroad Bridge to Otis St	-0.6	-0.2	-0.4	-0.2	-0.1
Otis St to Grove St	-0.5	-0.3	-0.2	-0.1	-0.1
Grove St to Pine Ave	-0.6	-0.3	-0.2	-0.1	-0.1
Pine Ave to Perkins Ave	-0.9	-0.5	-0.3	-0.2	-0.1
Perkins Ave to Plain St	-1.0	-0.8	-0.4	-0.5	-0.2
Plain Street to Sargent's Way	-0.9	-0.8	-0.7	-0.7	-0.6
Sargent's Way to K-Mart Plaza	-0.4	-0.2	-0.2	-0.2	-0.2



Flood Inundation Limit Comparisons for Belmont Ave (top) and Plain Street/Sargent's Way. Boundaries shown are existing conditions (red); predicted inundation boundary after installation of the Ellis Brett gate alone (light blue); predicted boundary for the composite alternative (dark blue).

1 Project Background & Purpose

Salisbury Brook flows approximately 4.7 miles from its headwaters at the Brockton Reservoir (located in the Town of Avon) through multiple impoundments within D.W. Field Park until it joins with Trout Brook in the vicinity of downtown Brockton (see **Figure 1-1**). Salisbury Brook receives a significant flow contribution during storm events from Lovett Brook, which enters the Brook at Ellis Brett Pond in D.W. Field Park. It should also be noted that Lovett Brook receives a majority of the stormwater runoff from the Westgate Mall complex, which is a large expanse of impervious area located just west of D.W. Field Park.

After the Salisbury Brook's confluence with Trout Brook just upstream of the Grove Street Bridge within the southwestern corner of the City's downtown area, it becomes the Salisbury Plain River (hereafter, the River). The River continues to flow through the City of Brockton and into the towns of West Bridgewater and East Bridgewater for approximately 4.7 miles where it eventually meets the Matfield River.

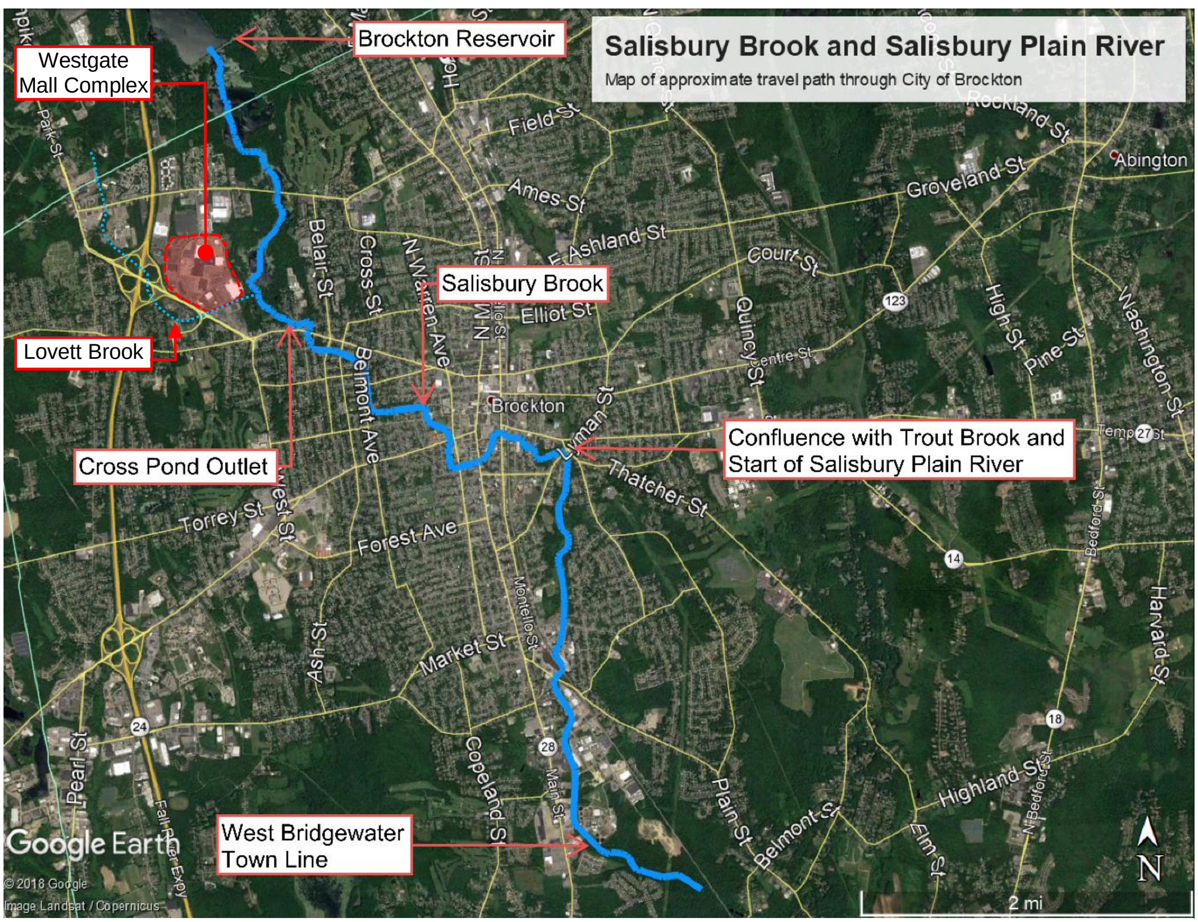


Figure 1-1. Aerial view of Brockton, MA, including the location of the Salisbury stream corridor within the current limit of study.

Both waterways have experienced significant flooding throughout history and will continue to do so given the current trend of more frequent and intense rainfall events. Due to the significant amount of development and infrastructure surrounding the waterways, many bridges and residential/commercial structures are at risk of experiencing considerable damage as these normally placid waterways surge above their banks during rainfall events.

Therefore, the ultimate goal of Fuss & O'Neill's hydrologic and hydraulic analysis of both waterways will be to develop a more up-to-date and accurate riverine model that can not only replicate flood conditions experienced during flood present and future flood events but also be used to develop flood mitigation measures and recommendations.

The first step in this process is to develop what is known as a "Duplicate Effective Model." Currently, flood mapping exists for the section of the Brook and River between Cross Pond (which is the last impoundment in a series of seven impoundments along the Brook in D.W. Field Park) and the City of Brockton's community boundary with West Bridgewater. This mapping is documented within FEMA's Flood Insurance Study (FIS) for Plymouth County, Massachusetts dated November 4, 2016. Flood mapping and information included in this document, however, are based on outdated hydrologic and hydraulic data. Hydrologic data (including precipitation information) is based on a hydrologic analysis performed by USDA NRCS in 1972; the hydraulic or riverine model is based on a steady-state HEC-2 hydraulic model developed by USACE in 1977. Given the steady-state nature of the model and use of outdated hydrologic data (including precipitation), FEMA's model provides an outdated and simplistic representation of flooding that is experienced through the river system. As an initial step in the modeling process, Fuss & O'Neill replicated FEMA's steady-state model of Salisbury Brook and the Salisbury Plain River.

Fuss & O'Neill then developed a refined and more up-to-date hydrologic and hydraulic model that identifies flood conditions under present-day and future conditions to better identify areas of flooding and more accurately assess flood impacts along the Brook and River. The refined hydraulic model's limits extend from the Brockton Reservoir, located in the Town of Avon, to a point approximately 3,800 feet downstream of Brockton's community boundary with West Bridgewater. While the purpose of this report is to document Fuss & O'Neill's development of this refined model and to summarize its results, the purpose of the model is not only to function as a tool to better identify existing public infrastructure and privately-owned development within flood risk locations but also to allow for the prioritization of such flood risks and the development of nature-based and green infrastructure solutions to reduce flooding. These latter goals will be the subject of subsequent tasks within the City's MVP Action Grant project.

2 Initial HEC-RAS Model Development

2.1 Effective Flood Study

The current flood zone mapping for Salisbury Brook and Salisbury Plain River is based upon a detailed flood study which is documented in FEMA's Flood Insurance Study (FIS) for Plymouth County, Massachusetts (All Jurisdictions) dated November 4, 2016. The flood zone boundaries, which include Zone AE in addition to the River's floodway, are depicted on the following Flood Insurance Rate Maps (FIRMs) for Plymouth County (Massachusetts):

- FIRM No. 25023C0158J (dated July 17, 2012);

- FIRM No. 25023C0159J (dated July 17, 2012);
- FIRM No. 25023C0167J (dated July 17, 2012); and
- FIRM No. 25023C0186J (dated July 17, 2012).

For the Salisbury Brook and Salisbury Plain River, the widths of the floodway and 1-percent annual chance flood elevations depicted within the FIS are based on flood elevations and floodway data computed from a hydrologic model developed by USDA NRCS in 1972 and a HEC-2 hydraulic model developed by USACE in 1977. The extents of the floodway and 1-percent annual change flood are based on flood elevations determined at each cross section and interpolated between cross sections using topographic maps created from digital orthophotography at a scale of 1:5,000.

Copies of the pertinent FIRMs (listed above) and water surface profiles from the FIS are included as *Figures 1A through 1F and Figures 2A-2E* within Fuss & O'Neill's detailed technical memorandum.

2.2 Hydrologic & Hydraulic Analyses

2.2.1 Limits of Analysis

For the purposes of this analysis, a hydraulic model of Salisbury Brook and Salisbury Plain River was generated from a point just downstream of Elmwood Avenue in Brockton to FEMA Section D in West Bridgewater. FEMA Section D is located approximately 3,800 feet downstream of Brockton's community boundary with West Bridgewater. Consequently, the overall stretch of the Salisbury Brook and Salisbury Plain River being analyzed is approximately 31,500 feet (or 5.97 miles) in length.

2.2.2 Duplicate Effective Model

Prior to the development of updated or more-detailed flood modelling along a waterway that has been studied by FEMA, FEMA requires the creation of a Duplicate Effective Model that matches the channel and structure geometry, flows, and water surface elevations of the most recent existing FEMA model documented in the Flood Insurance Study (FIS) for Plymouth County, Massachusetts (All Jurisdictions) dated November 4, 2016. This is required to ensure that the effective model's input data has been transferred correctly from FEMA's hydraulic back-up data and to ensure that the revised data will be integrated into the effective data to provide a continuous FIS model upstream and downstream of the sections of waterway(s) to be revised.

Hydraulic Back-up Data (Obtained from FEMA)

In order to create the Duplicate Effective Model for Salisbury Brook and Salisbury Plain River from Cross Pond, the upstream limit of analysis in Brockton, to FEMA Section D, the downstream limit of analysis in West Bridgewater, Fuss & O'Neill obtained hydraulic back-up data (from FEMA) used to create the hydraulic model that is currently reflected within the Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRMs) for Plymouth County, Massachusetts (All Jurisdictions).

This information includes river channel geometry, Manning's coefficients used in the river channel and its overbank areas, bridge/culvert geometry, peak flows utilized throughout the stretch of the flooding sources being analyzed, and floodway limits and pertinent input data. The input data was received in HEC-2 format.

The following peak discharges, as determined from our review of the hydraulic back-up data received from FEMA, were utilized for the 10-, 2-, 1-, and 0.2-percent annual chance floods:

Table 2-1. Summary of Discharges for Salisbury Brook and Salisbury Plain River within Limit of Study

Flooding Source and Location	Drainage Area (Square Miles)	10-Percent Discharge (cfs)	2-Percent Discharge (cfs)	1-Percent Discharge (cfs)	0.2-Percent Discharge (cfs)
Salisbury Brook at Cross Pond (FEMA Section 92.00)	5.9	325	520	610	860
Salisbury Brook at Newbury Street (FEMA Section 62.00)	7.1	370	590	690	980
Salisbury Brook at Trout Brook Confluence (FEMA Section 52.0)	7.7	390	630	740	1,040
Salisbury Plain River at Grove Street (FEMA Section 7.00)	14.2	1,180	1,730	1,950	2,410
Salisbury Plain River at Meadow Lane (FEMA Section 2.40)	16.4	1,310	1,870	2,160	2,660

According to the FIS, the hydrology of the Salisbury Brook and Salisbury Plain River was based on discharge-frequency relationships determined from methodology developed by the USDA NRCS which analyzed anticipated rainfall and the resulting runoff (U.S. Department of Agriculture, NRCS, August 1972). This methodology is referred to as the Rainfall Runoff Method.

- For the Salisbury Brook, the Rainfall Runoff Method was used to determine peak flows for the watersheds contributing flow to the impoundments within D.W. Fields Park in addition to Lovett Brook. D.W. Fields Park is located upstream of the project's limit of detailed hydraulic analysis and contains the following impoundments: Brockton Reservoir, Waldo Lake, Upper Porter Pond, Lower Porter Pond, Thirty Acre Pond, Ellis Brett Pond, and Cross Pond. Peak flows generated by these watersheds were routed through these impoundments taking into consideration that peak flows from the series of ponds would be substantially reduced because of the attenuation of flood waters supplied by these impoundments (i.e. Brockton Reservoir and Waldo Lake). The outflows from Cross Pond (during the 10%, 2%, 1%, and 0.2% annual chance flood events) was then added to the Lovett Brook peak flows and applied to the hydraulic model's upstream limit of analysis. Peak flows at downstream locations within the Brook were then calculated using drainage-area relationships. All cross-section information within the Brook's channel were field surveyed by Harry R. Feldman, Inc., under subcontract to CDM.

- For the Salisbury Plain River, peak flows were first determined by graphically adding peak flows from the Salisbury Brook and Trout Brook just downstream of its confluence. Peak flows for Trout Brook were also determined by the USDA NRCS Rainfall Runoff Method. Downstream of the confluence, peaks flows for the Salisbury Plain River were determined using drainage-area relationships and graphically adding in peak flows from Salisbury Brook and Trout Brook. All cross-section information within the River's channel were field surveyed by Harry R. Feldman, Inc., under subcontract to CDM.

Rainfall data for the selected recurrence intervals were obtained from U.S. Weather Bureau publications (U.S. Department of Commerce, 1963; U.S. Department of Commerce, 1964).

Vertical Datum Conversion

Contour and water surface information included within the hydraulic back-up data provided by FEMA utilize elevations relative to the National Geodetic Vertical Datum of 1929 (NGVD29). However, contour and water surface information reflected within the current FIS and FIRMs utilize elevations relative to the North American Datum of 1988 (NAVD88). For comparison purposes, water surface elevations generated within the Duplicate Effective Model can be converted to NAVD by subtracting 0.80 feet from the NGVD values as recommended by the current county-wide FIS (with an effective date of November 4, 2016).

Hydraulic Methodology

In order to create the Duplicate Effective Model of the Salisbury Brook and Salisbury Plain River within the Project's limit of analysis, the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS) software, Version 5.0.6, was utilized.

Since water surface elevations included within the flood profiles of the Salisbury Brook and Salisbury Plain Rivers were generated from a HEC-2 hydraulic model, the steady flow option that allows conveyance calculations to be performed between every coordinate point in the cross section overbanks was selected since this is similar to the approach used in HEC-2.

Model Results & Comparison

Based on information provided within the hydraulic back-up (input) data received from FEMA, the Duplicate Effective Model within our limit of study includes:

- 142 cross sections; and
- 36 bridges.

The following table provides a comparison between 1-percent annual chance base flood water surface elevations (WSEs) computed by HEC-RAS for the Salisbury Brook and Salisbury Plain River with those water surface elevations currently listed in the FIS for the county of Plymouth, Massachusetts (March 2, 2009):

Table 2-2. Duplicate Effective Model vs. Flood Insurance Study

1-Percent Annual Chance Base Flood WSE Comparison

Cross Section	River Station[1]	Duplicate Effective Base Flood WSE (ft.) NGVD29	Duplicate Effective Base Flood WSE (ft.) NAVD88	FIS Base Flood WSE (ft.) NAVD88	WSE Difference (ft.)
I	67.0	123.89	123.09	123.1	0.0
H	63.0	123.08	122.28	122.3	0.0
G	61.0	121.91	121.11	121.2	-0.1
F	59.0	121.42	120.62	120.9	-0.3
E	57.0	121.16	120.36	120.4	0.0
D	43.0	105.15	104.35	104.1	+0.3
C	41.0	104.97	104.17	103.9	+0.3
B	38.0	104.79	103.99	103.8	+0.2
A	31.0	103.43	102.63	102.4	+0.2
V	7.00	87.18	86.38	86.6	-0.2
U	6.00	84.35	83.55	83.6	0.0
T	5.00	84.22	83.42	83.5	-0.1
S	4.00	84.14	83.34	83.4	-0.1
R	3.40	84.02	83.22	83.3	-0.1
Q	3.10	83.92	83.12	83.2	-0.1
P	3.00	83.91	83.11	83.2	-0.1
O	2.95	83.74	82.94	83.0	-0.1
N	2.85	83.26	82.46	82.5	+0.0
M	2.83	82.51	81.71	81.6	+0.1
L	2.60	80.39	79.59	79.5	+0.1
K	2.30	79.00	78.20	78.1	+0.1
J	2.00	77.56	76.76	76.8	0.0
I	1.10	73.33	72.53	72.6	-0.1
H	1.00	71.17	70.37	70.3	+0.1
G	0.10	71.05	70.25	70.0	+0.3
D[2]	0.028	66.70	65.90	65.9	0.0

Notes:

1 River station represents the river section reference number provided within FEMA's hydraulic back-up data.

2 This section represents the downstream boundary of our detailed analysis. Downstream boundary flood surface elevations from FEMA Section D were utilized as obtained from FEMA's FIS flood profiles at this location. It should be noted, however, that actual flood elevations may be higher than listed in FEMA's FIS due to a potential discrepancy between flows utilized by West Bridgewater. According to FEMA's FIS, the flows for the 10%, 2%, 1%, and 0.2% annual chance flood events are 591 cfs, 809 cfs, 924 cfs, and 1139 cfs, respectively in West Bridgewater. These flows are significantly less than those listed for the section of the River in Brockton.

For this analysis, it was determined that a 0.5-foot WSE differential between results obtained from the Duplicate Effective Model and base flood WSEs provided within the FIS was within acceptable limits considering that the existing model was generated using HEC-2. As illustrated in **Table 2-2**, the 100-year water surface elevations approximate those listed within the FIS to within 0.3 feet or less. The reason for this minor discrepancies has to do with overall computation differences between the HEC-2 and HEC-RAS hydraulic programs, in particular, the differences in bridge/culvert modeling routines between the two programs.

Further figures depicting the limit of the 100-year flood, as determined through our duplicate effective analysis and water surface profiles for the 10-, 50-, 100-, and 500-year floods are included in Fuss & O'Neill's technical memorandum along with a summary of results from the HEC-RAS analysis.

3 Refined Hydrologic & Hydraulic Modeling

3.1 Watershed Based Hydrologic Analysis

Evaluation of current flooding conditions requires the quantification of flow that is discharged to the Salisbury Brook/Salisbury Plain River riverine system by contributing watershed areas and tributaries during the various storm events analyzed. Given the significant length of the river system being analyzed and the numerous tributaries and locations where flow enters the river system, the overall area (watershed) draining to the river system was subdivided into smaller watershed areas in order to gain a better understanding of the timing relationships that exist between the numerous subwatersheds and tributaries within the limits of the study.

Flood flow hydrographs for each of these subwatershed areas were then generated using the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) program (Version 4.2.1). HEC-HMS is a commonly used computer program that simulates the precipitation-stormwater runoff process and computes watershed discharge, flood storage, and water flow diversions. The model computes stormwater runoff hydrographs accounting for soil-water infiltration, runoff transform (the method of transforming excess precipitation into surface runoff), the amount of impervious area within the subwatershed, the amount of time that it takes for water to flow from the most remote point in a subwatershed to the river system, and the distribution of rainfall intensity over time. The HEC-HMS model also requires a specific unit hydrograph method to be specified. The United States Department of Agriculture (USDA) Soil Conservation Service (SCS) Unit Hydrograph was specified for these analyses.

3.1.1 Subwatershed Delineation

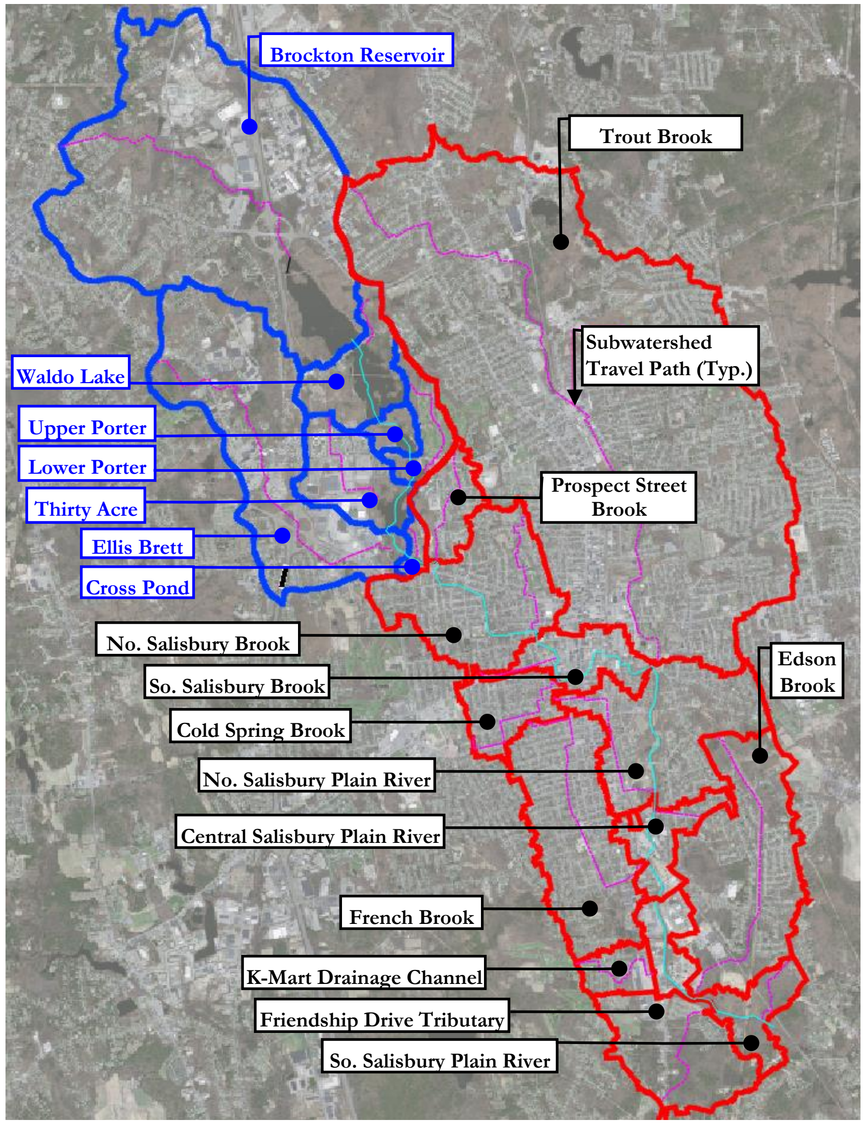


Figure 3-1. D.W. Field Park Impoundment Watershed Delineations

The 19 subwatersheds that contribute flow to the Salisbury Brook/Salisbury Plain River riverine system were delineated as shown in **Figure 3-1.** These subwatersheds were initially delineated using StreamStats, a commonly used program developed by the United States Geological Survey (USGS), but were subsequently reviewed for accuracy using 2-foot contour data obtained from the National Oceanic and Atmospheric Association (NOAA) Data Access Viewer[1] in addition to City-wide base and storm drain mapping provided by the City. Where necessary, minor modifications were then made to the boundaries of subwatershed areas. The delineations of the subwatershed areas associated with the impoundments upstream of Cross Pond (in D.W. Field Park) were not modified from those documented within Fuss & O'Neill's previous *Watershed Based Hydrologic/Hydraulic Analysis for Ellis Brett Pond Dam (November 2018)*[2]. These subwatersheds are shown in blue in **Figure 3-1.** The subwatersheds that are shown in red, downstream of Cross Pond, were delineated as part of this analysis.

Table 3-1 lists the subwatersheds that contribute flow to the Salisbury Brook and Salisbury Plain River

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[1] The contour information obtained from NOAA was derived from a combination of 2013-2014 USGS Coastal and Marine Geology Program (CMGP) LiDAR Data, which was acquired and processed to assist in the evaluation of storm damage and erosion as part of the USGS Hurricane Sandy response along the Atlantic Seaboard, and 2011 USGS LiDAR data

[2] Watershed Based Hydrologic/Hydraulic Analysis & Spillway Design for Ellis Brett Pond Dam, November 2018, Fuss & O'Neill, Inc.

within the limits of study.

Table 3-1. Subwatershed Summary

Subwatershed Name	Area (sq. mi.)
Brockton Reservoir	3.44
Waldo Lake	0.44
Upper Porter Pond	0.10
Lower Porter Pond	0.23
Thirty Acre Pond	0.44
Ellis Brett Pond[1]	1.67
Cross Pond	0.06
Prospect Street Brook	0.28
No. Salisbury Brook (at Newbury Street)	0.97
Cold Spring Brook	0.32
So. Salisbury Brook (at Trout Brook)	0.33
Trout Brook	7.04
No. Salisbury Plain River (at Arlene Street)	1.00
French Brook	1.05
Central Salisbury Plain River (at Meadow Lane)	0.28
K-Mart Drainage Channel	0.16
Edson Brook	1.24
Unnamed Brook at Friendship Drive	0.68
So. Salisbury Plain River (Downstream End)	0.49
Total Area:	**20.21**

Note:

[1] The Ellis Brett Pond Subwatershed contains Lovett Brook and its contributing drainage area which consists of a signification portion of the Westgate Mall complex.

3.1.2 Soil Loss Methodology

Not all precipitation that falls to the surface is direct runoff that is conveyed to rivers and streams. Some of it is intercepted or captured by localized depressions, some of it evaporates, and some of it infiltrates into the ground. For purposes of this analysis, interception and evaporation were conservatively ignored since the amount of runoff that is actually intercepted or evaporated during a critical period of major rainfall is likely insignificant in respect to the amount of runoff generated by contributing subwatershed areas.

The Green and Ampt Soil Loss Method[3] was used to approximate the amount of precipitation that infiltrates in each subwatershed such that runoff hydrographs for each subwatershed could be generated. This approach required the estimation of soil characteristics such as initial moisture content, maximum

[3] Green, W.H., and G.A. Ampt. (1911). Studies on Soil Physics, Part I, The Flow of Air & Water Through Soils. *Journal of Agricultural Science*, Volume 4, No. 1, pp 1-24.

attainable saturated content, suction head (capillary action of soil pores), and saturated hydraulic conductivity based on soil texture, hydrologic soil group, depth to any impermeable layer, and depth to groundwater. The USDA Natural Resources Conservation Service (NRCS) Web Soil Survey (WSS) was used to calculate the percentages of soil textures, hydrologic soil groups, and the weighted average depth to both impermeable layer and groundwater. The weighted suction pressure, porosity (or maximum attainable saturated content), and hydraulic conductivity for each watershed were computed from generalized values listed in *Table 2* of the *HEC-HMS Technical Reference Manual* (USACE, March 2000). **Table 3-2** provides typical soil loss characteristics for various soil textures present in the study area.

Table 3-2. Typical Soil Loss Parameters Based on Soil Texture

Soil Texture	Green and Ampt Soil Loss Parameters[1]		
	Saturated Content	Suction Head (Inches)	Saturated Hydraulic Conductivity (Inches/Hour)
Sand	0.437	4.17	8.27
Loamy Sand	0.437	5.59	2.41
Sandy Loam	0.453	8.74	1.02
Loam	0.463	12.40	0.52
Silt Loam	0.501	15.91	0.27

Note:

[1] Typical values obtained from Table 12 of the HEC-HMS Technical Reference Manual.

After reviewing the values listed above for saturated hydraulic conductivity, Fuss & O'Neill determined that saturated hydraulic conductivity values could be further refined based upon the amount of varying hydrologic soil groups in each subwatershed as well as the weighted average depth to groundwater and to any restrictive soil layer. The hydrologic condition of a soil reflects its runoff potential. In general, soils with a 'Type A' hydrologic group classification have a high rate of infiltration when thoroughly wet; soils with a 'Type B' hydrologic group classification have a moderate rate of infiltration when thoroughly wet; soils with a 'Type C' hydrologic group classification have a slow rate of infiltration when thoroughly wet; and soils with a 'Type D' hydrologic group classification have a very slow rate of infiltration when thoroughly wet. Using the weighted average depth to any restrictive soil layer, the weighted average depth to the water table throughout the year, and the hydrologic soil group classifications for soils in each subwatershed, the tables included as part of **Table 3-3** published in USDA NRCS's *Chapter 7 of Part 630 Hydrology National Engineering Handbook (NEH, May 2007)* were used to compute the weighted saturated hydraulic conductivity for each subwatershed.

Table 3-4 summarizes the weighted Green and Ampt parameters used to generate runoff hydrographs for each subwatershed.

Refer to Fuss & O'Neill's detailed technical memorandum for output obtained from the USDA NRCS WSS documenting the percentages of soil types, hydrologic soil groups, soil textures, and the weighted average depths to restrictive soil layer and groundwater within each subwatershed, as well as documentation supporting the development of weighted Green and Ampt soil loss parameters for each subwatershed in the HEC-HMS analysis.

Table 3-3. Typical Saturated Hydraulic Conductivities Based on Hydrologic Soil Group and Depth to Groundwater (as obtained from USDA NRCS NEH)

Table 7–1 Criteria for assignment of hydrologic soil groups when a water impermeable layer exists at a depth between 50 and 100 centimeters [20 and 40 inches]

Soil property	Hydrologic soil group A	Hydrologic soil group B	Hydrologic soil group C	Hydrologic soil group D
Saturated hydraulic conductivity of the least transmissive layer	>40.0 μm/s (>5.67 in/h)	≤40.0 to >10.0 μm/s (≤5.67 to >1.42 in/h)	≤10.0 to >1.0 μm/s (≤1.42 to >0.14 in/h)	≤1.0 μm/s (≤0.14 in/h)
	and	and	and	and/or
Depth to water impermeable layer	50 to 100 cm [20 to 40 in]	50 to 100 cm [20 to 40 in]	50 to 100 cm [20 to 40 in]	<50 cm [<20 in]
	and	and	and	and/or
Depth to high water table	60 to 100 cm [24 to 40 in]	60 to 100 cm [24 to 40 in]	60 to 100 cm [24 to 40 in]	<60 cm [<24 in]

Table 7–2 Criteria for assignment of hydrologic soil groups when any water impermeable layer exists at a depth greater than 100 centimeters [40 inches]

Soil property	Hydrologic soil group A	Hydrologic soil group B	Hydrologic soil group C	Hydrologic soil group D
Saturated hydraulic conductivity of the least transmissive layer	>10 μm/s (>1.42 in/h)	≤10.0 to >4.0 μm/s (≤1.42 to >57 in/h)	≤4.0 to >0.40 μm/s (≤0.57 to >0.06 in/h)	≤0.40 μm/s (≤0.06 in/h)
	and	and	and	and/or
Depth to water impermeable layer	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]
	and	and	and	and/or
Depth to high water table	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]

Notes:

[1] Based on the results of model calibration efforts, the upper value listed in the ranges provided for each hydrologic soil group were used in computing the weighted saturated hydraulic conductivity for each subwatershed.

[2] The saturated hydraulic conductivity value used for sandy soils with a Type 'A' hydrologic soil group classification and a depth to water ranging between 20 and 40 inches (Table 7-1) was 8.27 inches per hour, as it is listed as having a value greater than 5.67 inches per hour. 8.27 inches per hour was assumed to be reasonable given the typical maximum value for sandy soils based on soil texture. All soil textures other than sand were assigned a value of 5.67 when meeting these same criteria.

[3] The saturated hydraulic conductivity value used for sandy soils with a Type 'A' hydrologic soil group classification and a depth to water greater than 40 inches (Table 7-2) was 5.67 inches per hour, as it is listed as having a value greater than 1.42 inches per hour. 5.67 inches per hour was assumed to be reasonable given that values in Table 7-2 are lower than those in Table 7-1. All soil textures other than sand were assigned a value of 1.42 when meeting these same criteria.

Table 3-4. Weighted Green and Ampt Soil Loss Parameter Summary

Subwatershed	Subwatershed Area (sq. mi.)	Green and Ampt Soil Loss Parameters			
		Initial Content[1]	Saturated Content	Suction (Inches)	Saturated Hydraulic Conductivity (Inches/Hour)
Brockton Reservoir	3.44	0.3350	0.4467	7.6663	2.5582
Waldo Lake	0.44	0.3334	0.4445	7.0579	4.2587
Upper Porter Pond	0.10	0.2677	0.3569	5.0280	4.6878
Lower Porter Pond	0.23	0.3171	0.4228	7.0672	2.9467
Thirty Acre Pond	0.44	0.3312	0.4416	6.5004	2.3901
Ellis Brett Pond	1.67	0.3362	0.4483	7.7408	2.1980
Cross Pond	0.06	0.3323	0.4431	6.7965	2.6350
Prospect Street Drainage Channel	0.28	0.3315	0.4420	6.4969	3.9569
No. Salisbury Brook (at Newbury Street)	0.97	0.3342	0.4456	7.2756	4.0483
Cold Spring Brook	0.32	0.3287	0.4383	5.8324	5.1651
So. Salisbury Brook (at Trout Brook)	0.33	0.3377	0.4502	8.1127	2.1417
Trout Brook	7.04	0.3322	0.4429	7.1801	2.530
No. Salisbury Plain River (at Arlene Street)	1.00	0.3302	0.4403	6.2170	4.1191
French Brook	1.05	0.3287	0.4382	5.9021	4.7578
Central Salisbury Plain River (at Meadow Lane)	0.28	0.3266	0.4354	5.8420	3.3014
K-Mart Drainage Channel	0.16	0.2970	0.3960	5.8117	3.0516
Edson Brook	1.24	0.3283	0.4377	7.7092	2.4028
Unnamed Brook at Friendship Drive	0.68	0.3272	0.4363	5.3264	3.4914
So. Salisbury Plain River (Downstream End)	0.49	0.3342	0.4456	8.0659	1.9103

Note:
[1] The initial content is a function of soil moisture at the beginning of the precipitation event. The initial content was conservatively assumed to be 75% of the saturated content.

3.1.3 Impervious Surface Area Percentages

Impervious surfaces prevent rainfall from entering the soil. As the amount of impervious surfaces within a subwatershed increases, the amount of stormwater runoff generated by that subwatershed also increases. In computing the amount of stormwater runoff generated by each subwatershed that contributes flow to the Salisbury Brook/Salisbury Plain River riverine system, the percentage of the subwatershed consisting of impervious area is required. Since soil loss calculations are not applied to impervious areas, precipitation that falls on these surfaces is considered excess precipitation that becomes direct runoff. Impervious cover percentages for each subwatershed were computed using the

1-meter 2005 Impervious Surface dataset available from MassGIS. Documentation supporting impervious area calculations is included in Fuss & O'Neill's detailed technical memorandum. Areas covered by open water were also added as impervious surfaces since these areas will not provide any infiltration of runoff. It was also conservatively assumed that any stormwater best management practices (BMPs) located throughout the overall watershed (e.g., detention or retention basins, subsurface infiltration systems, bioretention basins, etc.) would not provide significant attenuation or storage during the storm events analyzed. **Table 3-5** summarizes the percent imperviousness (including water) computed for each subwatershed.

Table 3-5. Impervious Surface Percentage Summary

Subwatershed	Subwatershed Area (sq. mi.)	Impervious Cover Percentage	Percentage of Open Water	Total Impervious Percentage[1]
Brockton Reservoir	3.44	26.6%	4.9%	31.5%
Waldo Lake	0.44	9.7%	29.6%	39.3%
Upper Porter Pond	0.10	11.3%	18.9%	30.2%
Lower Porter Pond	0.23	9.0%	5.3%	14.3%
Thirty Acre Pond	0.44	47.4%	9.8%	57.2%
Ellis Brett Pond	1.67	35.0%	0.2%	35.2%
Cross Pond	0.06	31.8%	1.0%	32.8%
Prospect Street Drainage Channel	0.28	35.9%	0.0%	35.9%
No. Salisbury Brook (at Newbury St.)	0.97	46.8%	0.0%	46.8%
Cold Spring Brook	0.32	49.2%	0.0%	49.2%
So. Salisbury Brook (at Trout Brook)	0.33	68.2%	0.0%	68.2%
Trout Brook	7.04	36.3%	0.5%	36.8%
No. Salisbury Plain River (at Arlene St.)	1.00	38.9%	0.5%	39.4%
French Brook	1.05	49.1%	0.1%	49.2%
Central Salisbury Plain River (at Meadow Lane)	0.28	61.2%	0.6%	61.8%
K-Mart Drainage Channel	0.16	49.7%	0.0%	49.7%
Edson Brook	1.24	22.7%	0.0%	22.7%
Unnamed Brook at Friendship Drive	0.68	19.4%	0.5%	20.0%
So. Salisbury Plain River (Downstream End)	0.49	27.3%	0.0%	27.3%
Totals:	**20.21**			**36.7%**

Note:
[1] The percentages of areas covered by open water were added to the impervious cover percentages computed based on the 2005 Impervious Surface dataset obtained from MassGIS.

As reflected in **Table 3-5**, the percentages of impervious surfaces within the subwatersheds draining to the Salisbury Brook/Salisbury Plain River riverine system vary between 14.3% and 68.2% with the overall percentage of impervious cover being approximately 36.7%. To put this value into perspective, the amount of surface runoff generated by a subwatershed generally doubles when the percentage of impervious surface within reaches between 10% and 20% according to an EnviroAtlas *Percent Impervious Area Fact Sheet*[4] published by the United States Environmental Protection Agency (USEPA). Therefore,

[4] *Percent Impervious Area Fact Sheet*, United States Environmental Protection Agency (April 2018) (https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/ESN/PercentImperviousArea.pdf)

even the more frequent rainfall events (i.e. the 2-year storm) can generate stormwater runoff volumes that result in elevated Brook and River water levels, impacts to storm drain systems that discharge to those waterways, and flooding to bordering buildings and infrastructure.

3.1.4 Time of Concentration Estimation

The time of concentration (T_C), is another hydrologic parameter that has an effect on the peak flood flow generated by a watershed area. Several methods have been developed for estimating the T_C. The Watershed Lag Method, developed by the USDA NRCS, was the method used in this analysis. The travel path representing the longest hydraulic flow path within the watershed to the point of analysis was determined using elevation data and aerial imagery. The average basin slope was then computed using multiple hydraulic paths chosen at representative locations throughout each subwatershed. The paths used to calculate the hydraulic length of each subwatershed are reflected in **Figure 3-1.**

Although this method computes each subwatershed's time of concentration, the time of concentration must then be converted to a lag time for use in HEC-HMS. Lag time is defined as the delay between the time that runoff from a rainfall event over a watershed begins until runoff reaches its maximum peak. Empirical evidence (Mockus 1957; Simas 1996) indicates that lag time is equal to 60% of the time of concentration. **Table 3-6** provides a summary of T_C and lag times computed for each subwatershed.

Table 3-6. Subwatershed Time of Concentration Summary

Subwatershed	Area (sq. mi.)	T_C (minutes)	Lag Time (minutes)[1]
Brockton Reservoir	3.44	294.1	176.46 [2]
Waldo Lake	0.44	53.8	32.28 [2]
Upper Porter Pond	0.10	48.6	29.16 [2]
Lower Porter Pond	0.23	177.0	106.20 [2]
Thirty Acre Pond	0.44	99.5	59.70 [2]
Ellis Brett Pond	1.67	352.7	211.62 [2]
Cross Pond	0.06	50.3	30.18 [2]
Prospect Street Drainage Channel	0.28	157.3	94.38
No. Salisbury Brook (at Newbury Street)	0.97	154.7	92.82
Cold Spring Brook	0.32	165.9	99.54
So. Salisbury Brook (at Trout Brook)	0.33	50.0	30.00
Trout Brook	7.04	677.3	406.38
No. Salisbury Plain River (at Arlene Street)	1.00	220.0	132.00
French Brook	1.05	359.3	215.58
Central Salisbury Plain River (at Meadow Lane)	0.28	79.4	47.64
K-Mart Drainage Channel	0.16	103.2	61.92
Edson Brook	1.24	318.8	191.28
Unnamed Brook at Friendship Drive	0.68	227.3	136.38
So. Salisbury Plain River (Downstream End)	0.49	76.8	46.08

Notes:

[1] In accordance with recommendations provided within the HEC-HMS Technical Reference Manual, the lag time for ungauged watersheds is generally 60% of the time of concentration.

[2] Time of concentrations for subwatersheds upstream of Elmwood Avenue (e.g. Brockton Reservoir, Waldo Lake, Upper Porter Pond, Lower Porter Pond, Thirty Acre Pond, Ellis Brett Pond, and Cross Pond) are documented within Fuss & O'Neill's previous *Watershed Based Hydrologic/Hydraulic Analysis for Ellis Brett Pond Dam (November 2018).*

Refer to Fuss & O'Neill's detailed technical memorandum for documentation supporting computed time of concentrations for each subwatershed downstream of Cross Pond. Time of concentrations for subwatersheds upstream of Cross Pond (including Brockton Reservoir, Waldo Lake, Upper Porter Pond, Lower Porter Pond, Thirty Acre Pond, Ellis Brett Pond, and Cross Pond) are documented within Fuss & O'Neill's previous *Watershed Based Hydrologic/Hydraulic Analysis for Ellis Brett Pond Dam (November 2018).*

3.1.5 Precipitation Data & Rainfall Distribution

It is important to understand flooding conditions along the Salisbury Brook/Salisbury Plain River riverine system across a range of rainfall events. The events analyzed in this study were the 2-, 10-, 50-, 100-, and 500-year, 24-hour storm events.

Rainfall hyetographs for each subwatershed for the present-day 2-year, 10-year, 50-year, 100-year, and 500-year, 24-hour storm events were generated from the latest 24-hour precipitation depths obtained from NOAA Atlas 14 using the NRCS Type III synthetic 24-hour rainfall distribution curve. In 2013 the National Oceanic and Atmospheric Administration (NOAA) released Atlas 14, a tool that revises rainfall/precipitation frequency estimates based upon the use of more up to date rainfall data. The estimates serve as an update to the U.S. Weather Bureau's Technical Paper No. 40 (TP-40) published in 1961, which had previously served as an important resource over the years for engineers, planners, and hydrologists.

24-hour total precipitation values for each of the flood events analyzed is included in **Table 3-7**, as obtained from NOAA's Precipitation Frequency Data Server in November 2019.

Table 3-7. NOAA Atlas Precipitation Frequency Estimates for Present-Day Rainfall Events in Brockton

Flood (Storm) Event Return Frequency	Annual Exceedance Probability	Precipitation[1]
2-Year, 24-Hour	50%	3.35 inches
10-Year, 24-Hour	10%	5.03 inches
50-Year, 24-Hour	2%	6.87 inches
100-Year, 24-Hour	1%	7.71 inches
500-Year, 24-Hour	0.2%	10.10 inches

Notes:
[1] Obtained from NOAA's Precipitation Frequency Data Server for Brockton, Massachusetts.

This report will refer to storm events by their return frequency, such as the 2-year, 10-year, 50-year, 100-year, and 500-year, 24-hour storms. However, it should be understood that a storm event with a 2-year return frequency is synonymous with a storm with a 50% annual exceedance probability; a 10-year storm is synonymous with a storm with a 10% exceedance probability, and so on as shown in **Table 3-7**.

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3.1.6 Runoff Production & Peak Flow Rate Summary

With the soil loss parameters, time of concentrations/lag times, impervious percentages, and rainfall distribution curves computed, runoff hydrographs for each subwatershed were then generated using HEC-HMS. **Table 3-8** summarizes peak inflow runoff rates from each of the subwatersheds for the 2-, 10-, 50-, 100-, and 500-year, 24-hour rainfall events. Watersheds for the seven subwatersheds upstream of Cross Pond that were previously modeled using HEC-HMS as documented within Fuss & O'Neill's previous *Watershed Based Hydrologic/Hydraulic Analysis for Ellis Brett Pond Dam (November 2018)* were also recalculated since rainfall data has been updated since the time of that analysis.

Table 3-8. Subwatershed Peak Flow Rate Summary for the 2-, 10-, 50-, 100-, and 500-Year, 24-Hour Flood Events

Subwatershed[1]	Area (sq. mi.)	Peak Flow 2-Year	Peak Flow 10-Year	Peak Flow 50-Year	Peak Flow 100-Year	Peak Flow 500-Year
Brockton Reservoir	3.44	347.9 cfs	581.5 cfs	904.2 cfs	1,073.4 cfs	1,581.4 cfs
Waldo Lake	0.44	159.9 cfs	240.1 cfs	355.0 cfs	425.2 cfs	628.3 cfs
Upper Porter Pond	0.10	29.3 cfs	44.0 cfs	67.3 cfs	83.0 cfs	127.6 cfs
Lower Porter Pond	0.23	14.8 cfs	27.1 cfs	51.2 cfs	65.0 cfs	107.3 cfs
Thirty Acre Pond	0.44	164.3 cfs	265.5 cfs	389.7 cfs	449.3 cfs	631.5 cfs
Ellis Brett Pond	1.67	166.7 cfs	284.4 cfs	436.5 cfs	509.4 cfs	747.0 cfs
Cross Pond	0.06	18.8 cfs	33.7 cfs	56.0 cfs	68.0 cfs	103.6 cfs
Prospect Street Drainage Channel	0.28	48.3 cfs	72.6 cfs	109.6 cfs	128.9 cfs	188.2 cfs
No. Salisbury Brook (at Newbury Street)	0.97	222.8 cfs	334.6 cfs	482.1 cfs	559.5 cfs	787.8 cfs
Cold Spring Brook	0.32	73.1 cfs	109.8 cfs	150.0 cfs	173.5 cfs	242.9 cfs
So. Salisbury Brook (at Trout Brook)	0.33	215.9 cfs	346.5 cfs	503.4 cfs	577.0 cfs	798.3 cfs
Trout Brook	7.04	464.7 cfs	751.9 cfs	1,119.3 cfs	1,303.0 cfs	1,854.7 cfs
No. Salisbury Plain River (at Arlene Street)	1.00	153.2 cfs	230.0 cfs	336.5 cfs	392.6 cfs	559.7 cfs
French Brook	1.05	144.1 cfs	216.4 cfs	299.4 cfs	345.2 cfs	474.6 cfs
Central Salisbury Plain River (at Meadow Lane)	0.28	130.3 cfs	198.2 cfs	288.4 cfs	329.9 cfs	458.8 cfs
K-Mart Drainage Channel	0.16	52.3 cfs	82.4 cfs	122.2 cfs	142.5 cfs	201.7 cfs
Edson Brook	1.24	86.0 cfs	156.6 cfs	257.9 cfs	310.2 cfs	477.6 cfs
Unnamed Brook at Friendship Drive	0.68	51.6 cfs	79.1 cfs	141.2 cfs	169.0 cfs	269.9 cfs
So. Salisbury Plain River (Downstream End)	0.49	103.5 cfs	215.9 cfs	369.8 cfs	448.2 cfs	693.9 cfs

Notes:
[1] Refer to ***Figure 3-1*** for a depiction of contributing subwatershed areas.

Hydrologic calculations and supporting output data (obtained from HEC-HMS) are included in within Fuss & O'Neill's detailed technical memorandum.

3.2 Existing Conditions Hydraulic Analysis

With flow hydrographs for each contributing subwatershed area generated for the 2-, 10-, 50-, 100-, and 500-year floods, HEC-RAS (Version 5.0.6) was used to apply these flow hydrographs and model hydraulics through the Salisbury Brook and Salisbury Plain River from Brockton Reservoir to a point approximately 3,800 feet downstream of Brockton's community boundary with West Bridgewater.

3.2.1 Hydraulic Model Development

As an initial step in the hydraulic modeling process, Fuss & O'Neill replicated FEMA's steady-state model of the Salisbury Brook and Salisbury Plain River as documented within FEMA's Flood Insurance Study (FIS) for Plymouth County, Massachusetts dated November 4, 2016 using HEC-RAS, Version 5.0.6. This model extended from Elmwood Avenue, the bridge just downstream of Cross Pond, to the City's boundary with West Bridgewater and was referred to as F&O's Duplicate Effective Model. While this duplicate effective model provided a good starting point for analysis as it included channel and bank topography for the Salisbury Brook and Salisbury Plain River along with bridge geometry (based on field survey previously performed by FEMA), the topographic data outside of the channel banks along with hydraulic information documented within the FIS are based on outdated information from FEMA's 1977 HEC-2 model. Subsequent to FEMA's 1977 hydraulic analysis, the Meadow Lane Bridge was removed and replaced with the Sargent's Way Bridge, a bridge that existed between Warren Avenue and Main Street was removed, and two small pedestrian bridges were constructed (one between the Brook's White Avenue and Route 28/Montello Street crossings and the other just downstream of the River's Grove Street crossing). Additionally, FEMA's hydraulic model of Salisbury Brook and Salisbury Plain River was run as a steady flow model. Steady flow models do not take into account the effects of in-channel and off-line storage in the attenuation of inflow. Steady flow models also do not take into account the varied timing of flow from contributing watersheds and tributaries. In other words, flow entering and being conveyed by the river system within an unsteady model varies with time while it does not within a steady state model. Therefore, an unsteady model should more accurately depict hydraulic conditions experienced during storm events as flows discharged to the river system from contributing subwatershed areas do actually vary with time. Any detention or attenuation of flows that may result from undersized bridges and/or culverts and significant flood storage areas will also be captured in an unsteady flow model, but not in a steady flow model.

Given the steady-state nature of FEMA's model of the Salisbury Brook and Salisbury Plain River and use of outdated hydrologic data (including precipitation), FEMA's model provides an outdated and simplistic representation of flooding that is experienced through the river system. To more accurately model hydraulics through the Salisbury Brook/Salisbury Plain River riverine system, an unsteady flow model representing present-day flooding conditions along the Brook and River (referred to herein as the refined hydraulic model) was developed by updating F&O's Duplicate Effective Model as follows.

- The Duplicate Effective Model was extended upstream to include the D.W. Field Park impoundments and eight (8) associated dam structures spanning from the Brockton Reservoir through Cross Pond as documented in Fuss & O'Neill's previous *Watershed Based Hydrologic/Hydraulic Analysis for Ellis Brett Pond Dam (November 2018);*

- 115 river cross sections were added to the model that were generated using high resolution river channel and overbank topography obtained from the latest available LiDAR mapping that was generated from a combination of 2011 and 2013-2014 United States Geological Survey (USGS) LiDAR data. The lateral extent of the cross sections were extended such that the left and right limits of each section reached an elevation greater than that of its corresponding 500-year flood elevation.
- Channel and bridge geometry was updated to reflect measurements taken in the field by Fuss & O'Neill in July 2008 and September 2019. All bridge openings and deck heights were updated with new dimensions as necessary if they differed from those used by FEMA in the Duplicate Effective Model. Channel dimensions were updated at sections immediately upstream and/or downstream to bridge crossings where it was determined that the channel's geometry was more similar to field dimensions obtained by Fuss & O'Neill at the bridge opening. For sections that were either inaccessible or further away from the bridge openings, FEMA's channel geometry was retained unless aerial imagery or photographs indicated otherwise.
- Channel and overbank roughness factors for each of the cross sections were modified as necessary based on field observations and the most recent aerial imagery. The following typical values were used for river channel and overbank areas as documented within *Table 3-1, Manning's 'n' Values* of USACE's *HEC-RAS River Analysis System Hydraulic Reference Manual (February 2016)*:
    - A channel roughness factor of 0.045 was used where the river channel was characterized as a clean, winding streams/channels with some weeds and stones scattered throughout;
    - Overbank/floodplain roughness factors of 0.013, 0.035, 0.070, and 0.100 were used depending on the type and thickness of vegetation that existed within channel overbank areas. A value of 0.013 was used for paved areas; a value of 0.035 was used for grassed areas (e.g., lawns); a value of 0.070 was used for areas covered by medium to dense brush and/or light brush and trees; and a value of 0.100 was used in areas that consisted of a heavy stand of trees.

The refined hydraulic model's limits extend from the Brockton Reservoir, located in the Town of Avon, to a point approximately 3,800 feet downstream of Brockton's community boundary with West Bridgewater. The overall refined model consists of 257 cross sections, 41 bridges/culverts and 8 inline/dam structures (dams). A cross section location map of the refined model is shown in **Figures 3-1, 3-2, and 3-3.** Additionally, a minimum initial condition flow of 25 cubic feet per second (cfs) was applied to the model to provide model stability during all analyzed flood events.

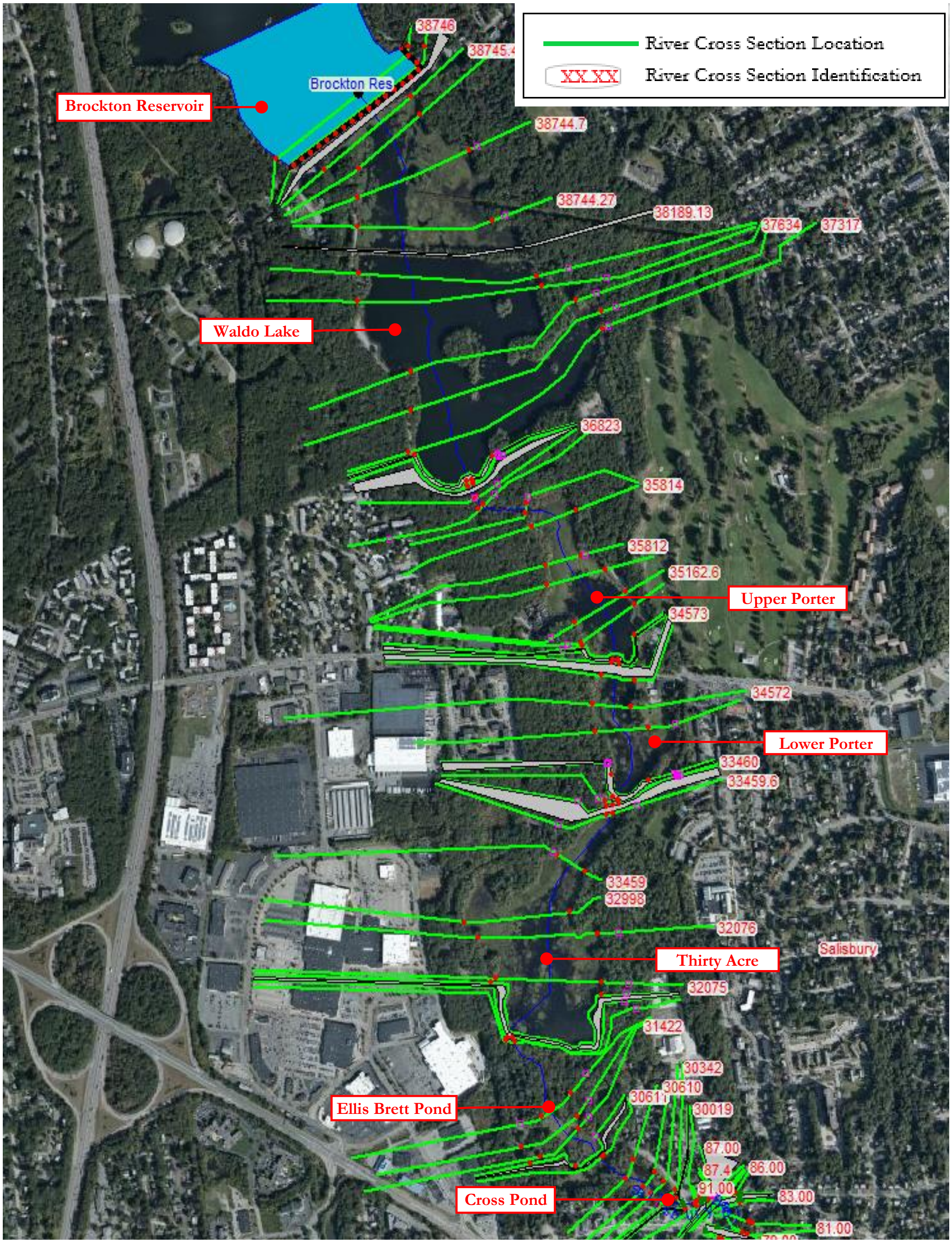

Figure 3-2. Hydraulic Model Analysis Cross Sections
Salisbury Brook and Salisbury Plain River from Brockton Reservoir through Cross Pond

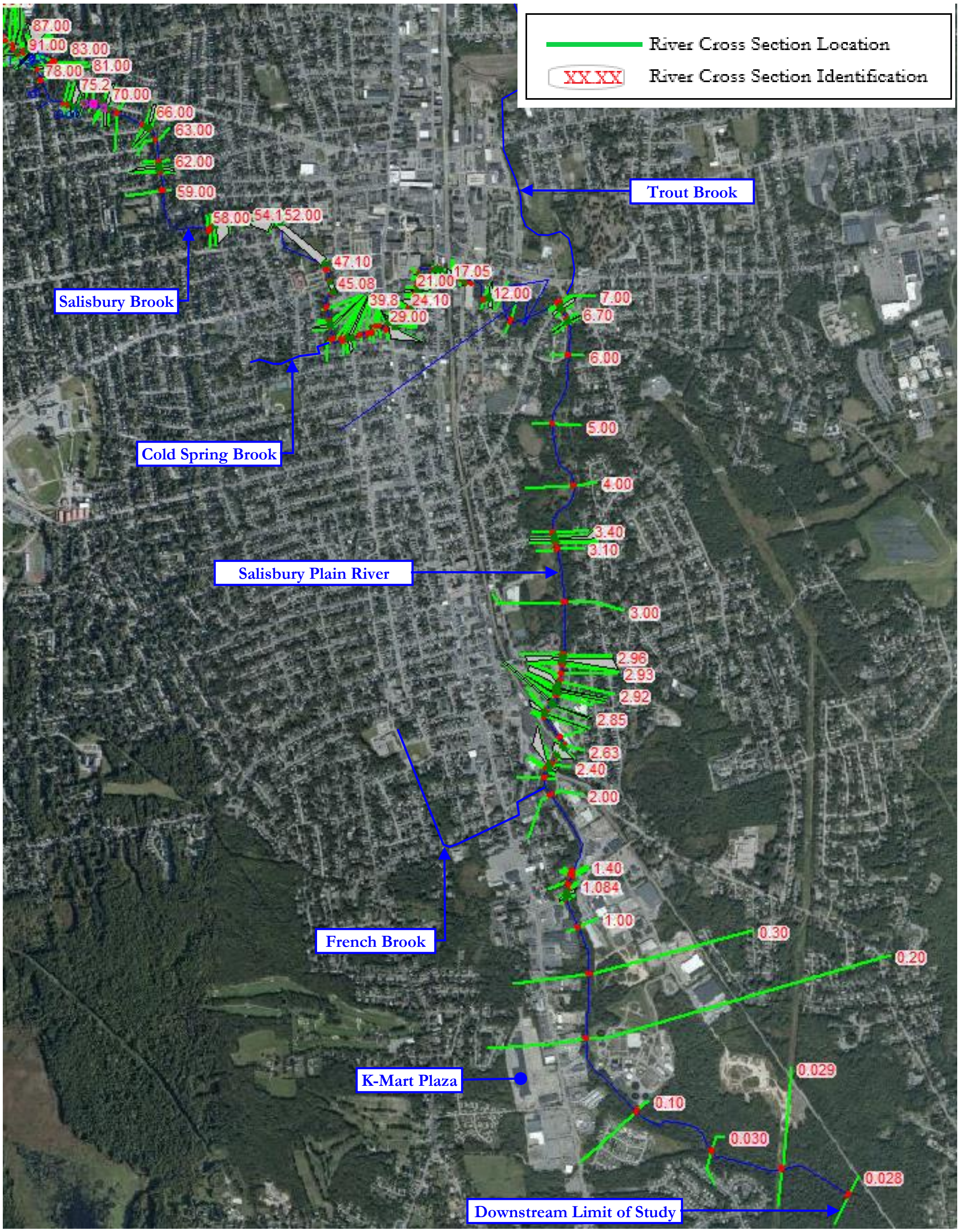

Figure 3-3. Hydraulic Model Analysis Cross Sections
Salisbury Brook and Salisbury Plain River from Cross Pond to West Bridgewater

3.2.2 Hydraulic Model Results

The results of our hydraulic analysis of the Salisbury Brook/Salisbury Plain River riverine system indicate that flooding will occur within multiple areas/neighborhoods throughout the City during the present-day 2-, 10-, 50-, 100-, and 500-year flood events. The frequency and extent of flooding varies and is described in more detail in the following sections.

Areas Prone to Frequent Flooding

The results of the hydraulic analyses of the Salisbury Brook/Salisbury River riverine system concluded that the following areas were most susceptible to frequent flooding (assumed to be the 2-year and 10-year floods). The limits of the 2-year and 10-year inundation areas are shown in associated illustrations in red and orange, respectively.

- Residential properties within the Belmont and Spring Street neighborhoods that directly border the Salisbury Brook between Ash Street and Green Street (referred to herein as Area 1). Refer to **Figure 3-4** for a depiction of the extents of flooding during the 2-year and 10-year floods.

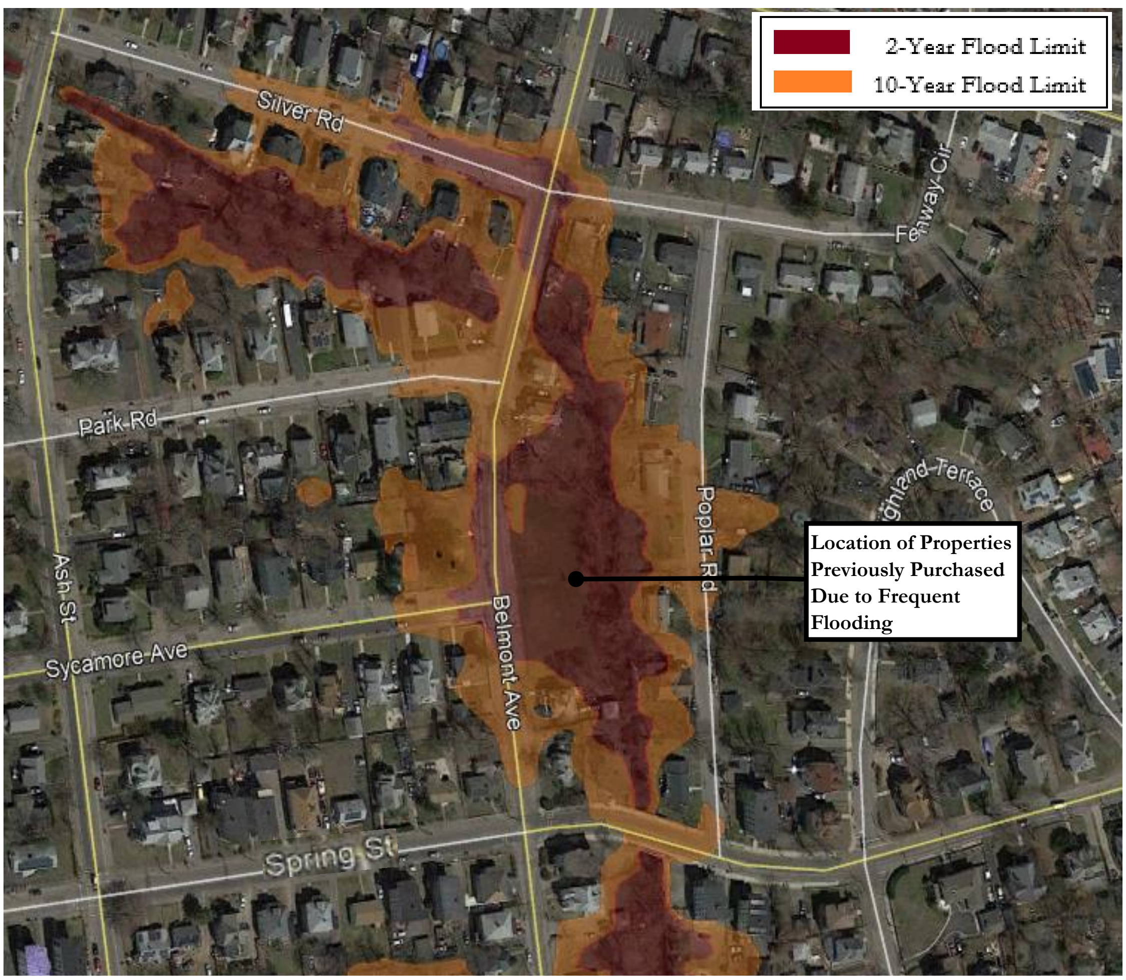

Figure 3-4. Area 1 Inundation Limits During the 2- and 10-Year Floods

- Residential properties that directly border the Brook between Green Street and the entrance of the culvert downstream of Newbury Street where the Brook makes a 90-degree bend before being conveyed underground to E.B. Keith Memorial Field (referred to herein as Area 2). This includes properties along Ellsworth Avenue. Refer to **Figure 3-5** for a depiction of the extents of flooding during the 2-year and 10-year floods.

Figure 3-5. Area 2 Inundation Limits During the 2- and 10-Year Floods

- The rear yards of residential properties that border Cold Spring Brook on the northwestern side of the Fuller Street/Winthrop Street intersection within the Ward 2 District (referred to herein as Area 3). Cold Spring Brook is an urbanized tributary to Salisbury Brook, which enters Salisbury Brook via a culvert located at a park that is just southwest of the Bartlett Street and Warren Avenue intersection. The analysis indicates that flooding will occur along Cold Spring Brook due to backwater impacts associated with elevated flood levels in Salisbury Brook. As shown in **Figure 3-6**, flooding of actual structures will not occur until the 10-year flood occurs although the rear yards of several properties will be inundated during the 2-year flood. It should be noted, however, that no process-based flood modeling was performed individually for Cold Spring Brook. Thus, the extent of flooding along Cold Spring Brook does not take into account any culvert restrictions associated with piped storm drain systems discharging to the Cold Spring Brook and as a result reflects flooding due to backwater only. view

Figure 3-6. Area 3 Inundation Limits During the 2- and 10-Year Floods

- Mixed-use properties along Salisbury Brook between Perkins Street and Otis Street (referred to herein as Area 4). Refer to **Figure 3-7** for a depiction of the extents of flooding during the 2-year and 10-year floods.

Figure 3-7. Area 4 Inundation Limits During the 2- and 10-Year Floods

- Residential properties along the Salisbury Plain River just upstream of its crossing with Perkins Avenue between Bridge Street and Perkins Avenue (referred to herein as Area 5) including the Walkover Commons apartment complex and homes near the intersection of

Riverview Street and Perkins Avenue as reflected in **Figure 3-8**. These structures are primarily impacted during the 10-year flood.

- Commercial properties that border the River between Perkins Avenue and Plain Street (referred to herein as Area 6) including the Churchill Linen Service, Churchill Supply Co., and Trojan Recycling as reflected in **Figure 3-8**.

Figure 3-8. Area 5 and 6 Inundation Limits During the 2- and 10-Year Floods

- Residential properties within the City's Campello Section that border French Brook in the vicinity of Brookside Avenue and Monarch Street (referred to herein as Area 7) as reflected in **Figure 3-9**.

- Commercial properties within the City's Campello Section that border the River between Watson Street and Holmes Street (referred to herein as Area 8) including the parking area of the High Point Treatment Center as reflected in **Figure 3-9**.

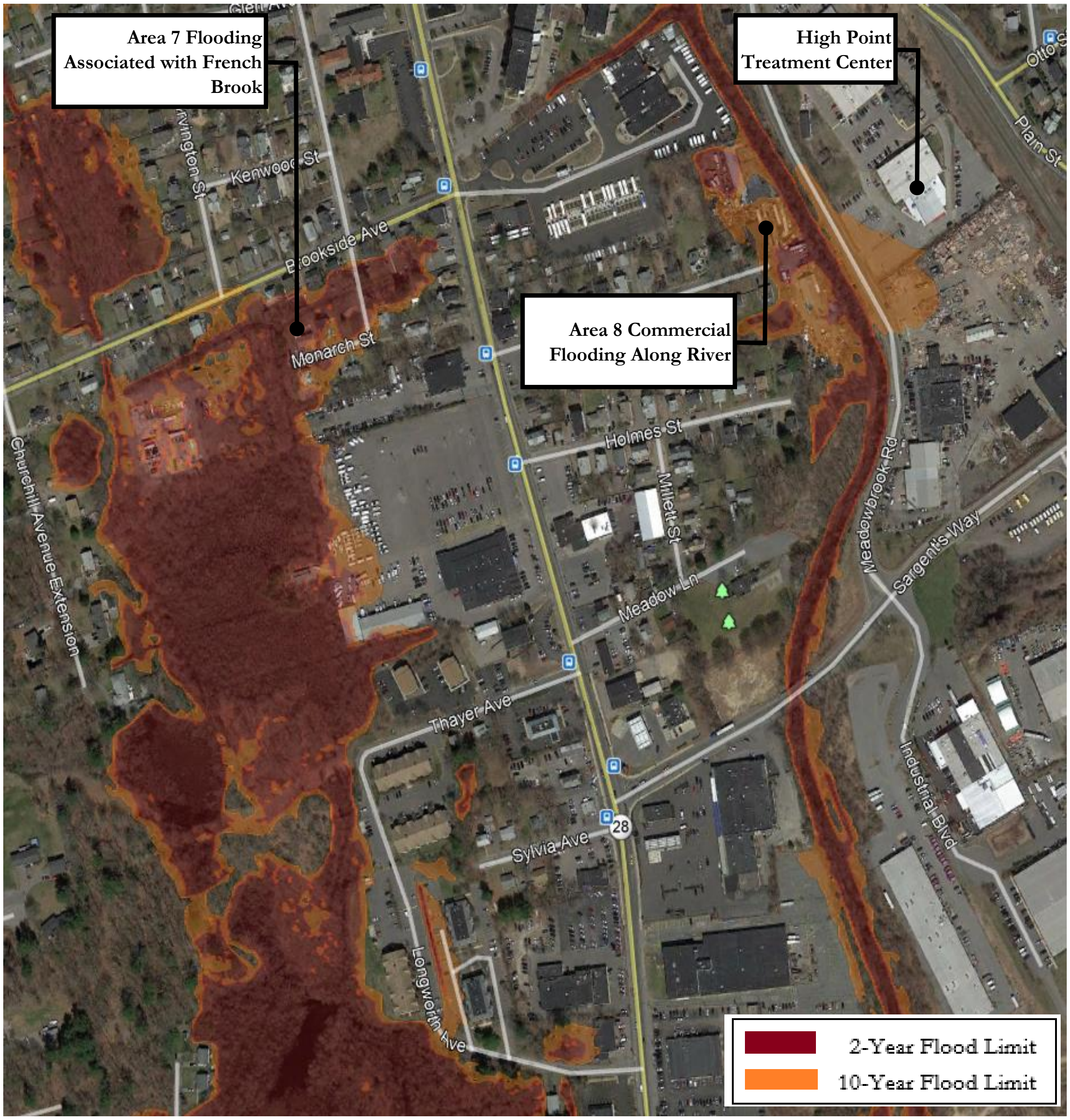

Figure 3-9. Area 7 and 8 Flooding During the 2- and 10-Year Floods

- Commercial properties within the City's Campello Section near the K-Mart plaza (referred to herein as Area 9) including the K-Mart parking lot, the rear of the Bradford Trailer Sales parking lot that borders the River, and the rear of New England Road Equipment parking area. Refer to **Figure 3-10** for a depiction of the extents of flooding during the 2-year and 10-year floods

Figure 3-10. Area 9 Flooding During the 2- and 10-Year Floods

Bridges along the Salisbury Brook and Salisbury Plain River do not overtop during the 2-year flood although water levels within the Brook come to within less than six inches of the roadway surface at Belmont Avenue. However, several bridges throughout the river system come extremely close to overtopping or do overtop during the 10-year flood event such as: Prospect Street, the private bridge just upstream of Moraine Street, Belmont Avenue, Spring Street, Carleton Street, North Arlington Street/Newbury Street, Pine Avenue, Perkins Avenue, and the private bridges downstream of Perkins Avenue (between Perkins Avenue and the railroad bridge).

Flooding also occurs throughout George Snow Park during the 10-year flood as shown in **Figure 3-11.** However, flooding at this location does not impact any surrounding structures during the more frequent

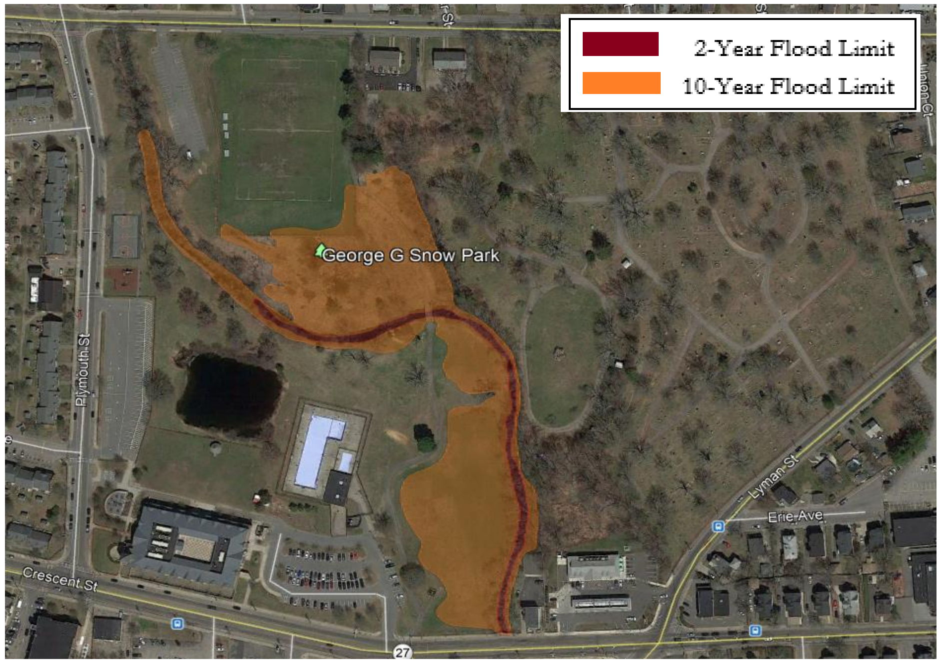

Figure 3-11. George Snow Park Flooding During the 2- and 10-Year Floods

flood events. It should be noted that the limits of flooding throughout the park area along Trout Brook were delineated similarly to Cold Spring Brook, using backwater elevations obtained at the confluence of Trout Brook with Salisbury Brook. Although flow contributions from the Trout Brook subwatershed were applied to the hydraulic model of the Salisbury Brook/Salisbury Plain River riverine system, an individual hydraulic model of Trout Brook was not generated as part of this study. It should also be noted that Snow Park has historically been a location of flood storage and should remain such. A review of the City's 1898 historical plat maps (obtained from www.historicmapworks.com) revealed that Snow Park was once Salisbury Lake. Flows from Trout Brook entered Salisbury Lake prior to being discharged downstream to Salisbury Brook/Salisbury Plain River. Subsequent to 1898, it appears that the lake was filled in resulting in a loss of floodplain storage for Trout Brook and potentially the loss of flow attenuation for flows entering Salisbury Brook. Refer to **Figure 3-12** for a depiction of the lake as it existed back in 1898.

Figure 3-12. 1898 Historic Plat Map of George Snow Park Area

Full-scale figures showing the inundation limits for the 2- and 10-year floods have been provided within **Appendix A**. Refer to **Appendix A** for flood profiles and output summary tables supporting the HEC-RAS analyses performed for the 2- and 10-year flood events.

Additional Areas Prone to Flooding During Larger Magnitude Flood Events

The results of the hydraulic analyses also concluded that not only did the extent and magnitude of flooding increase during the 50-, 100-, and 500-year flood events within the previously identified areas of frequent flooding, but the following areas emerged as additional areas that are susceptible to flooding during these larger flood events. The limits of the 50-, 100-, and 500-year inundation areas are shown in associated illustrations in yellow, dark green, and light green, respectively. The 2- and 10-year floods are also included in red and orange, respectively, for reference purposes.

- An area along Salisbury Brook between Pleasant Street and Ash Street, referred to herein as Area 10, appears to experience significant flooding during flood events with a magnitude equal to or greater than the 50-year flood. During the 500-year flood event, the area of flooding at this location extends as far as 1,100 feet from the Brook towards Park Road as shown in **Figure 3-13**. The limited capacity of the Moraine Street and Ash Street bridges/culverts appears to be a significant factor in elevated flood levels at this location.

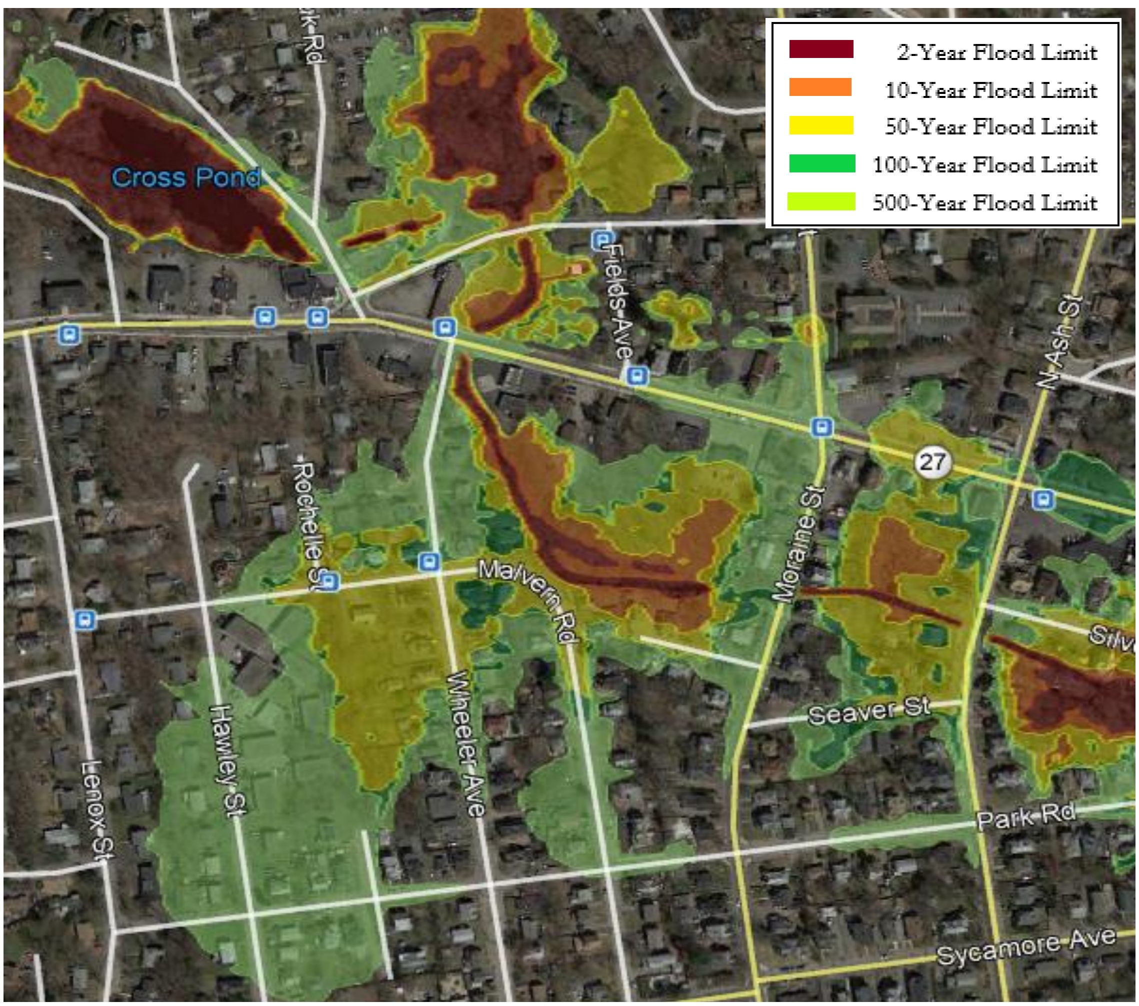

Figure 3-13. Area 10 Flooding During the 2-, 10-, 50-, 100-, and 500-Year Flood Events

- An area along the western banks of Salisbury Brook between Spring Street and Ellsworth Street, referred to herein as Area 11, appears to experience significant flooding during flood events with a magnitude equal to or greater than the 50-year flood. This area borders the area identified as Area 2 in the previous section. During the 50-year flood event and greater, the area of flooding at this location extends as far as 700 feet from the Brook encompassing the Bent Playground as shown in **Figure 3-14**. The combination of limited channel capacity along Ellsworth Avenue, ineffective hydraulics due to the sharp 90-degree bend downstream of Newbury Street, and the limited capacities of the bridges/culverts between North Arlington and the culvert that conveys flow underground to E.B. Keith Memorial Field appear to be significant factors in elevated flood levels at this location.

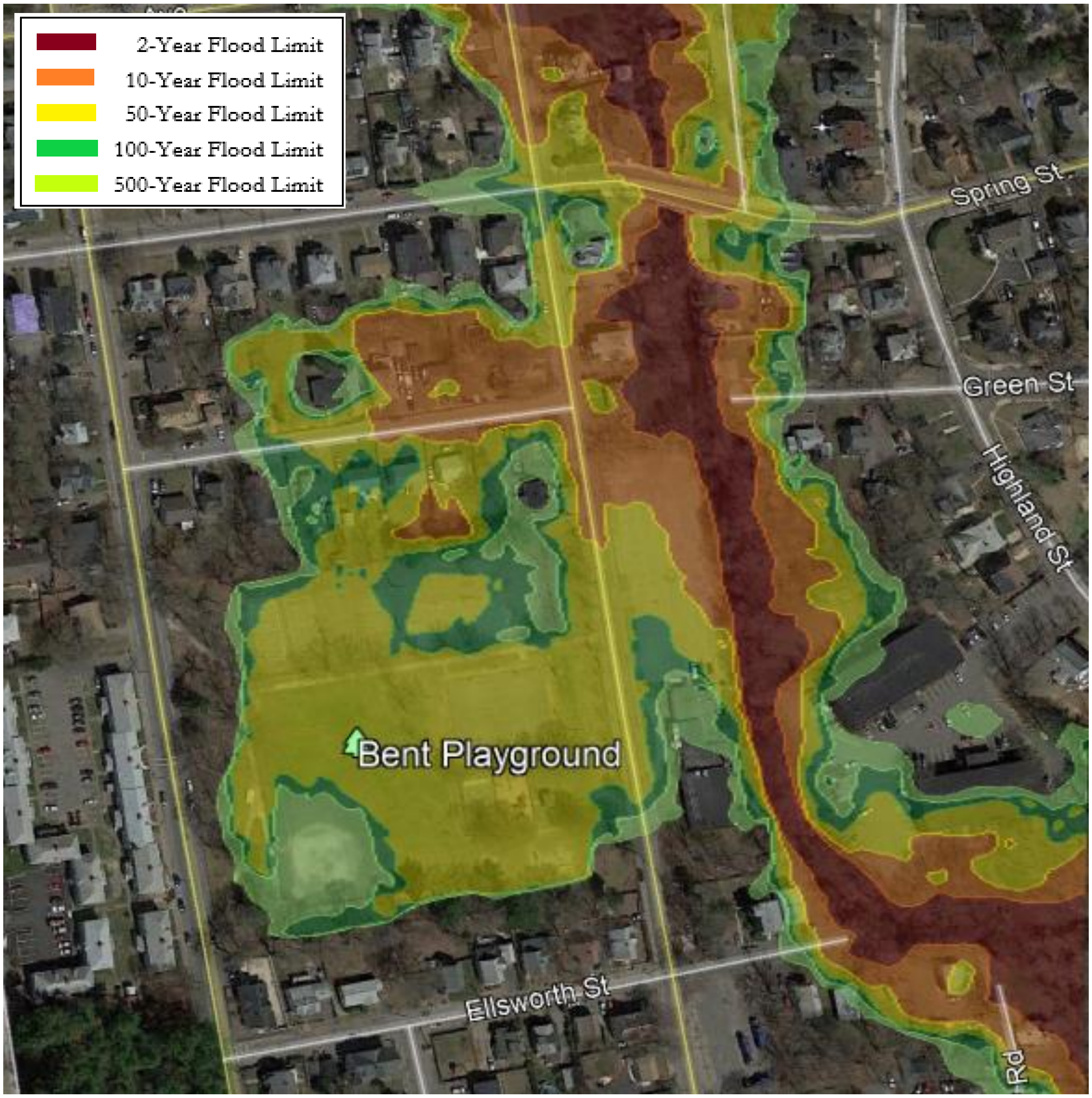

Figure 3-14. Area 11 Flooding During the 2-, 10-, 50-, 100-, and 500-Year Flood Events

* An area along Salisbury Brook between Newbury Street and Belmont Street (referred to herein as Area 12), which includes West Elm Street and the Eldon Keith Memorial Field, appears to experience flooding during flood events with a magnitude equal to or greater than the 50-year flood. Flooding at this location occurs when the amount of flow that is discharged through the Brook exceeds the capacity of the culvert located downstream of Newbury Street that conveys flow underground to E.B. Keith Memorial Field. Flow overtops the banks of the Brook at the culvert entrance and flows overland across West Elm Street and the Eldon Keith Memorial Field as shown in **Figure 3-15**. It is likely that backup of the storm sewer system on West Elm also occurs during smaller events (such as the 10-year storm) resulting in localized roadway flooding in the vicinity of the underground culvert.

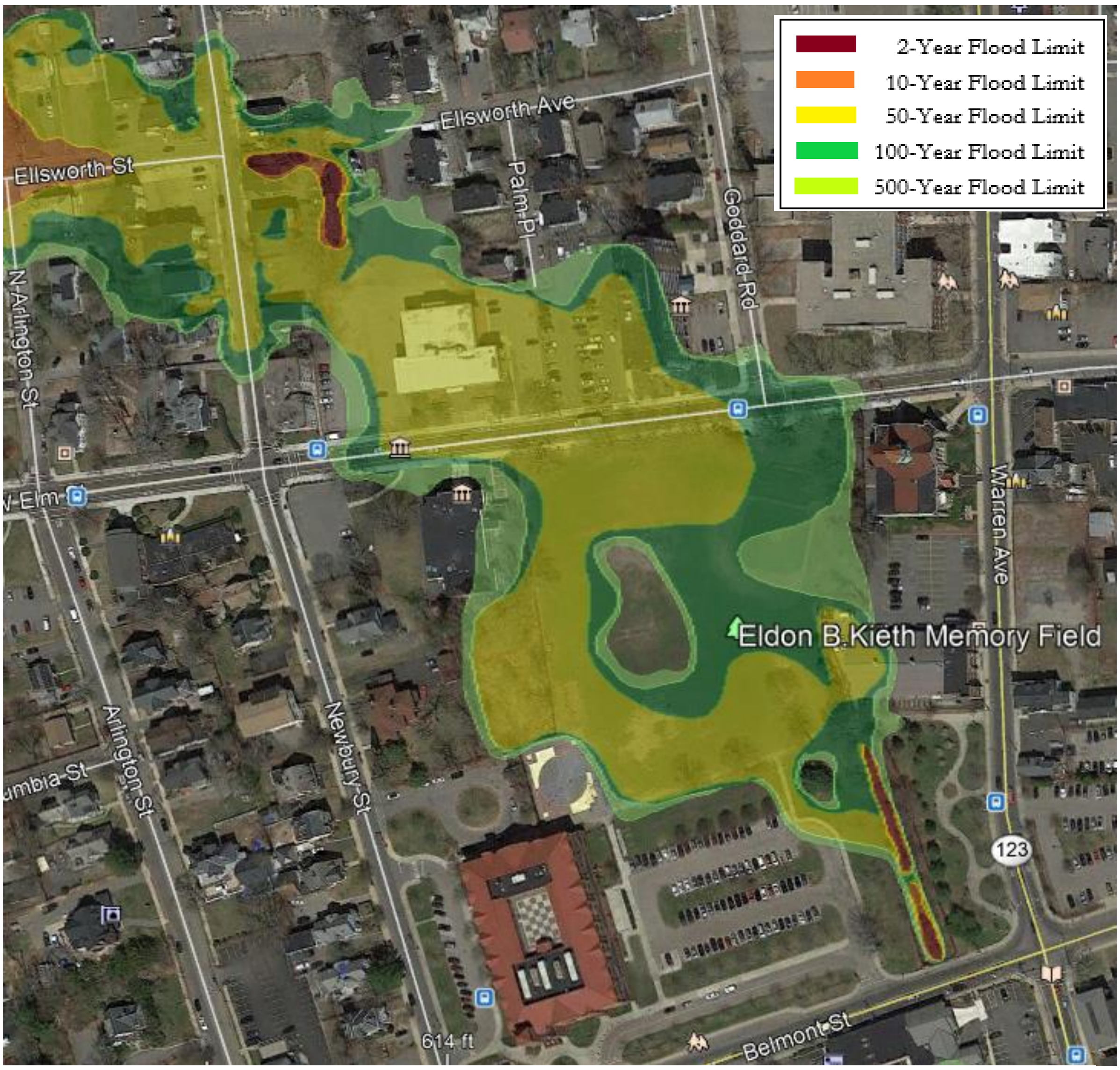

Figure 3-15. Area 12 Flooding During the 2-, 10-, 50-, 100-, and 500-Year Flood Events

It should also be noted that Eldon Keith Memorial Field was historically a location of flood storage. A review of the City's 1898 historical plat maps (obtained from www.historicmapworks.com) revealed that Eldon Keith Memorial Field and the abutting property to the north of West Elm Street were once two ponds/lakes: Howard's Pond and Leach's Pond. Subsequent to 1898, it appears that the lakes were filled in resulting in a loss of floodplain storage and peak flow attenuation for the section of Salisbury Brook upstream of Newbury Street. The ponds were replaced with an underground culvert that hydraulically connects flow from the Brook at the Ellsworth/Newbury Street area to the section of the Brook downstream of Eldon Keith Memorial Field. Refer to **Figure 3-16** for a depiction of the ponds as they existed in 1898.

- An area along the Brook within Downtown Brockton between Belmont Street and Perkins Street

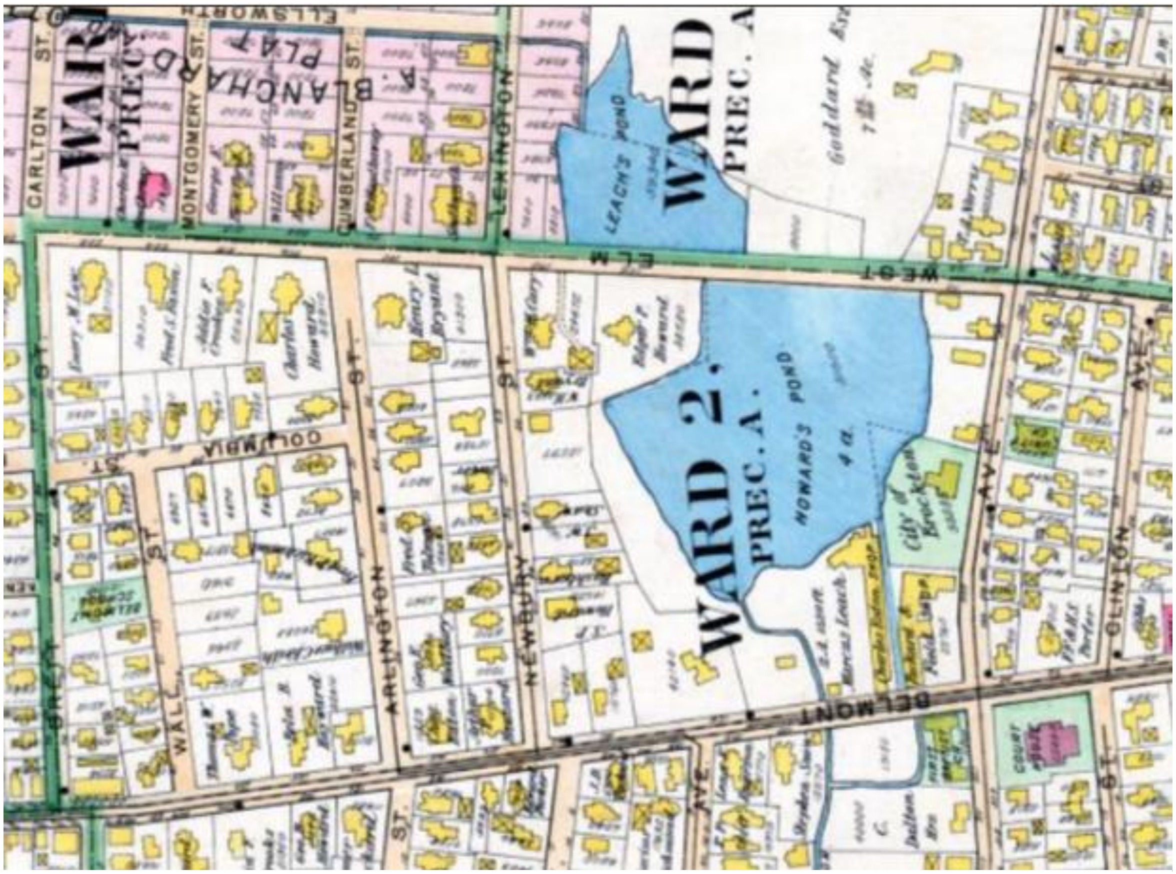

Figure 3-16. Area 12 Flooding During the 2-, 10-, 50-, 100-, and 500-Year Flood Events

referred to herein as Area 13. Although this area experiences some flooding during the 2- and 10-year floods, the extent and magnitude of flooding is more significant during floods with a magnitude greater than the 10-year flood as shown in **Figure 3-17**. Flooding at this location encompasses the section of Route 27 (Crescent Street) that passes beneath the railroad bridge. Although the model does not show flooding at this location during storm events of a lesser magnitude than the 50-year storm, it is likely that flooding at this location may occur more frequently if catch basins at this location discharge to the Brook (as backwater from the Brook may impact the capacity of the associated storm drain system).

Figure 3-17. Area 13 Flooding During the 2-, 10-, 50-, 100-, and 500-Year Flood Events

Full-scale figures showing the inundation limits for the 50-, 100- and 500-year floods for the areas discussed in this section in addition to the areas of more frequent flooding as noted in the previous section have been provided within **Appendix A**. Refer to **Appendix A** for flood profiles and output summary tables supporting the HEC-RAS analyses performed for the 50-, 100-, and 500-year flood events.

Additionally, it was understood that several properties along French Brook experienced flooding during significant rainfall events. French Brook is a tributary that enters the River just south of Plain Street. Although flow contribution from the French Brook subwatershed was accounted for in the hydraulic model of the Salisbury Brook/Salisbury Plain River riverine system, a detailed hydraulic model of French Brook was not prepared as part of this study. However, to approximate flooding along French Brook due to backwater impacts that would be experienced at the brook's confluence with Salisbury Plain River, water surface elevations in French Brook were approximated based on a simplistic model using HydroCAD. French Brook and its adjacent wetland system (extending as far south as Hayward Avenue) were modeled as a storage pond with a discharge culvert/outlet (passing beneath Main Street for a distance of approximately 700 feet) that provides a hydraulic connection to Salisbury Plain River. Using the hydrograph developed for the French Brook subwatershed (described in the previous sections), peak water surface elevations were determined for each of the five flood events. The results indicate that flows in French Brook exceed Main Street roadway elevations during the 100- and 500-year events.

Although water levels do not exceed the crest elevations of Main Street for the 2-, 10-, and 50-year flood events, it appears that the banks of French Brook are overtopped during these flood events resulting in flooding to several properties along the brook to the south of Brookside Avenue. Refer to **Appendix A** for documentation supporting the HydroCAD analysis of French Brook and a full-scale depiction of the inundation limits for French Brook**.**

During an Initial Stakeholder Meeting conducted with the City on September 10, 2019, an additional area of known flooding was discussed that is just outside of the City's corporate boundary limits. The area is located in West Bridgewater and is home to a trailer park community referred to as the Beacon Mobile Home Park. Although the hydraulic model reflected that the mobile community remained dry during the 2-year flood event, it confirmed that flooding is likely at this location during flood events with a magnitude equal to or greater than the 10-year flood. The extent of flooding during each analyzed flood event is shown in **Figure 3-18**.

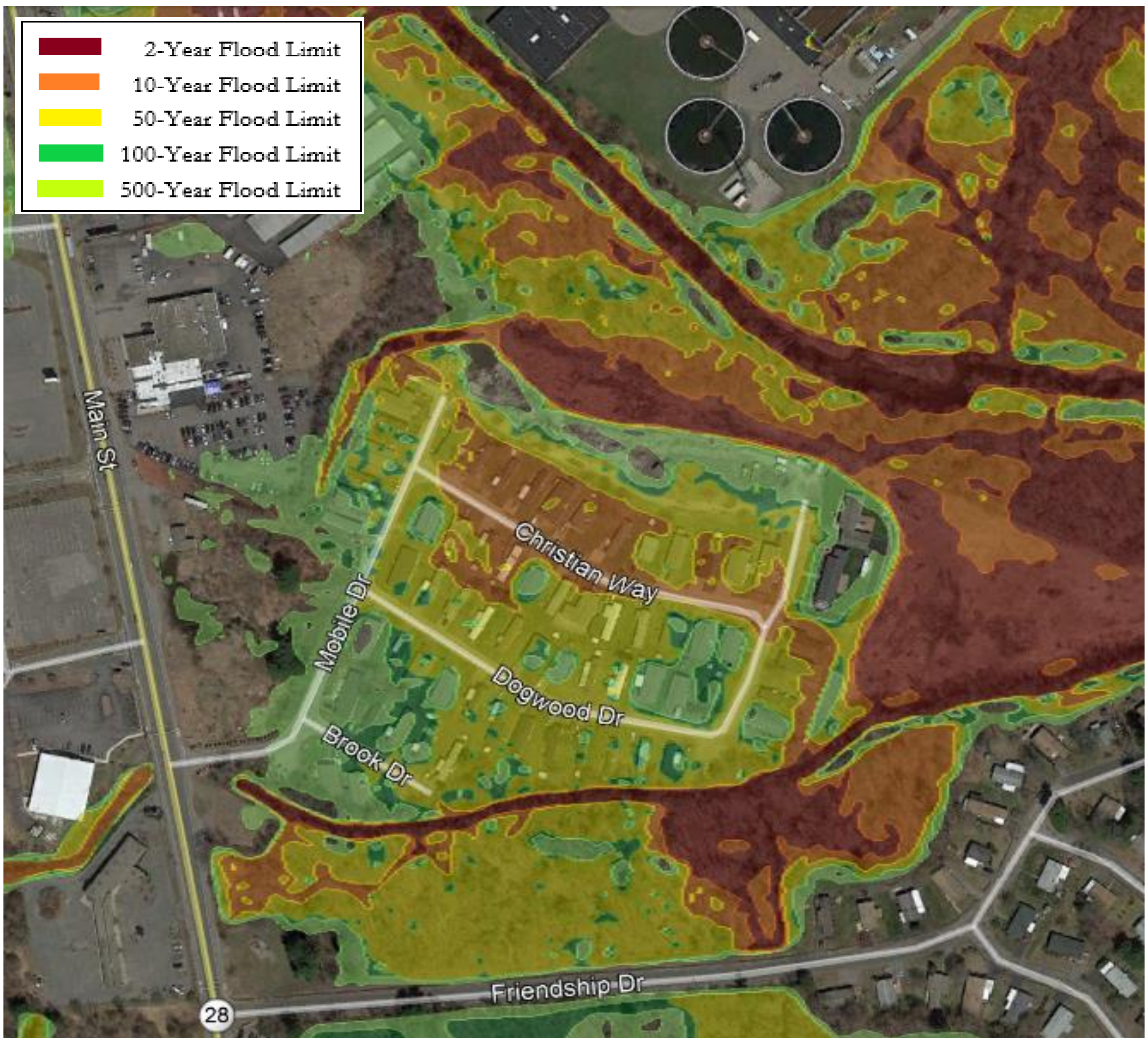

Figure 3-18. Bordering Mobile Home Community Flooding During the 2-, 10-, 50-, 100-, and 500-Year Flood Events

4 Potential Impact of Increased Precipitation

Should climate change predictions become realized and there is an increase in the intensity and frequency of larger storm events, flooding along the Salisbury Brook/Salisbury Plain River riverine system will only worsen. According to *USGS Scientific Investigations Report 2012-5109*[5], 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. Although there is also the potential for future development within the subwatersheds to occur, it is assumed (for purposes of this analysis) that such development will be designed to meet current storm water management standards and will not further impact peak flow magnification factors.

To assess the impacts that increased precipitation would have on flooding experienced throughout the Salisbury Brook/Salisbury Plain River riverine system, a flood magnification factor of 1.21 was applied to the rainfall runoff hydrographs generated by each contributing subwatershed (for each analyzed flood event) that were applied to the hydraulic (HEC-RAS) model. This represents projected impacts that each flood event will have in 2040.

While it is understood that the frequency and intensity of heavy precipitation events are projected to continue to increase over the 21st century, only the 2-year and 100-year existing and future (2040) flood events were compared for demonstration purposes. The following table summarizes anticipated increases in peak flow rates for each subwatershed during the existing and future 2- and 100-year floods assuming a future flood magnification factor of 1.21.

Future increases in flood flows during the 2- and 100-year flood events will result in the following impacts to water surface elevations in Salisbury Brook and Salisbury Plain River downstream of Cross Pond:

- an average increase in the 2-year flood elevation of 0.53 feet throughout Salisbury Brook (with increases ranging between 0.1 feet to 1.3 feet);
- an average increase in the 2-year flood elevation of 0.62 feet throughout Salisbury Plain River (with increases ranging between 0.3 feet to 1.0 feet);
- an average increase in the 100-year flood elevation of 0.82 feet throughout Salisbury Brook (with increases ranging between 0.1 feet to 2.6 feet); and
- an average increase in the 100-year flood elevation of 0.83 feet throughout Salisbury Plain River (with increases ranging between 0.4 feet to 1.9 feet).

The future 2-year flood will not substantially increase the extent or number of properties/structures inundated as compared to the existing 2-year flood, but will result in an average 6 to 7 inch increase in the depth of flooding to those properties that are currently flooded. Future 2-year flood conditions were approximated to be similar to present-day flooding conditions that would be experienced during an event falling between the 2-year and 10-year flood (e.g. the 5-year flood).

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[5] USGS, Magnitude of Flood Flows for Selected Annual Exceedance Probabilities in Rhode Island Through 2010, Scientific Investigations Report 2012-5109.

Table 4-1. Existing and Future Peak Flow Rate Summary Comparison for the 2- and 100-, 24-Hour Flood Events

Subwatershed[1]	Area (sq. mi.)	Existing Peak Flow 2-Year Storm	Future Peak Flow 2-Year Storm	Existing Peak Flow 100-Year Storm	Future Peak Flow 100-Year Storm
Brockton Reservoir	3.44	347.9 cfs	421.0 cfs	1,073.4 cfs	1298.8 cfs
Waldo Lake	0.44	159.9 cfs	193.5 cfs	425.2 cfs	514.5 cfs
Upper Porter Pond	0.10	29.3 cfs	35.5 cfs	83.0 cfs	100.4 cfs
Lower Porter Pond	0.23	14.8 cfs	17.9 cfs	65.0 cfs	78.7 cfs
Thirty Acre Pond	0.44	164.3 cfs	198.8 cfs	449.3 cfs	543.7 cfs
Ellis Brett Pond	1.67	166.7 cfs	201.7 cfs	509.4 cfs	616.4 cfs
Cross Pond	0.06	18.8 cfs	22.7 cfs	68.0 cfs	82.3 cfs
Prospect Street Drainage Channel	0.28	48.3 cfs	58.4 cfs	128.9 cfs	156.0 cfs
No. Salisbury Brook (at Newbury Street)	0.97	222.8 cfs	269.6 cfs	559.5 cfs	677.0 cfs
Cold Spring Brook	0.32	73.1 cfs	88.5 cfs	173.5 cfs	209.9 cfs
So. Salisbury Brook (at Trout Brook)	0.33	215.9 cfs	261.2 cfs	577.0 cfs	698.2 cfs
Trout Brook	7.04	464.7 cfs	562.3 cfs	1,303.0 cfs	1576.6 cfs
No. Salisbury Plain River (at Arlene Street)	1.00	153.2 cfs	185.4 cfs	392.6 cfs	475.0 cfs
French Brook	1.05	144.1 cfs	174.4 cfs	345.2 cfs	417.7 cfs
Central Salisbury Plain River (at Meadow Lane)	0.28	130.3 cfs	157.7 cfs	329.9 cfs	399.2 cfs
K-Mart Drainage Channel	0.16	52.3 cfs	63.3 cfs	142.5 cfs	172.4 cfs
Edson Brook	1.24	86.0 cfs	104.1 cfs	310.2 cfs	375.3 cfs
Unnamed Brook at Friendship Drive	0.68	51.6 cfs	62.4 cfs	169.0 cfs	204.5 cfs
So. Salisbury Plain River (Downstream End)	0.49	103.5 cfs	125.2 cfs	448.2 cfs	542.2 cfs

Notes:
[1] Refer to ***Figure 1-2*** for a depiction of contributing subwatershed areas.

The future 100-year flood, however, will have more substantial increases in the extent and number of properties/structures inundated as compared to the existing 100-year flood. A few notable locations where a substantial number of additional properties will be impacted due to increased flooding associated with the future 100-year flood are shown in **Figures 4-1, 4-2**. These locations include: the area along Salisbury Brook near the Hawley Street/Park Road intersection (within Area 10 flood limits) and within the Downtown area along Salisbury Brook near the Montello Street/ Lawrence Street intersection (within Area 13 flood limits). Future 100-year flood conditions are approximated to be similar to present-day flooding conditions that would be experienced during an event falling between the 100-year and 500-year flood with flooding depths and extents more closely aligning with the present-day 500-year flood.

Refer to **Appendix A** for full-scale figures showing the extents of flooding for the 2-year and 100-year existing and future floods.

The following profiles (shown in **Figures 4-3 and 4-4**) provide a visual comparison between 2-year and 100-year existing and future flood conditions for both the Salisbury Brook (upstream of Grove Street) and the Salisbury Plain River (downstream of Grove Street).

Figure 4-1. Area 10 Flood Extent Comparison between the Existing and Future 100-Year Flood Event

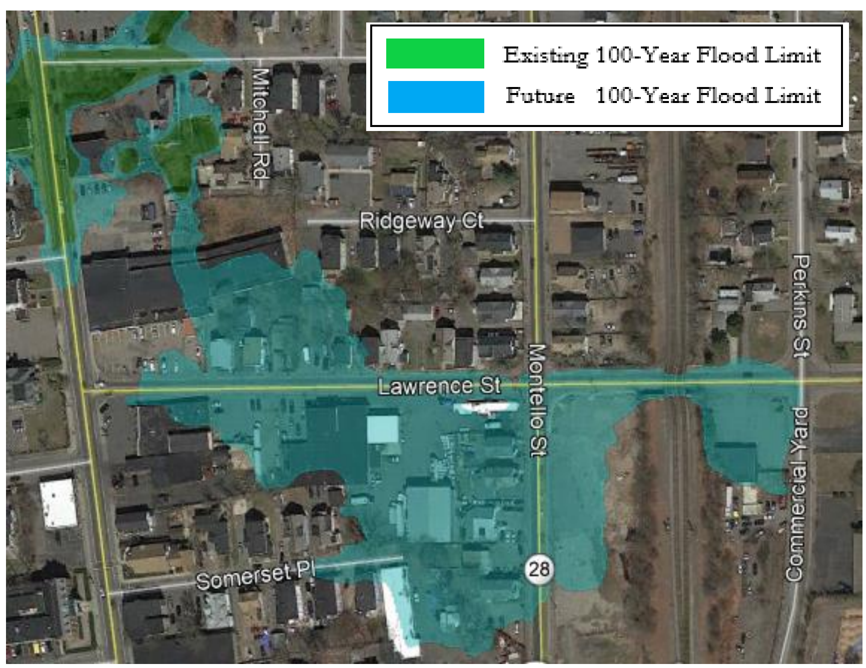

Figure 4-2. Area 13 Flood Extent Comparison between the Existing and Future 100-Year Flood Event

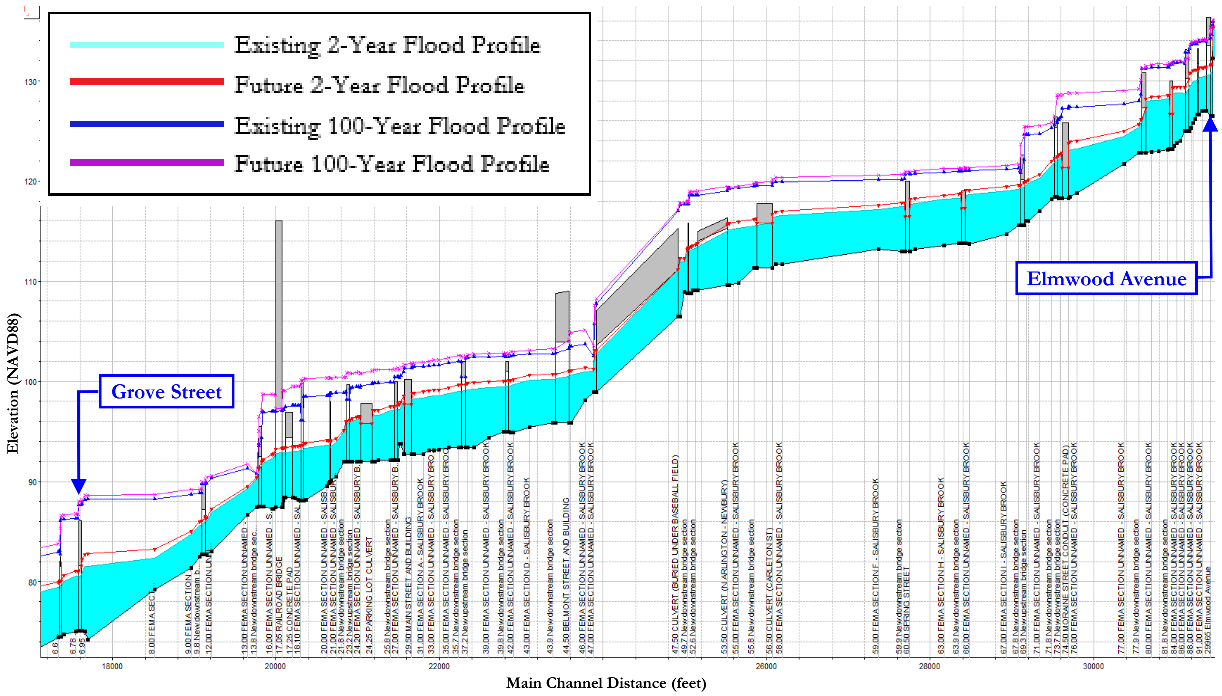

Figure 4-3. Salisbury Brook Water Surface Profile Comparison between the Existing and Future 2- and 100-Year Flood Events

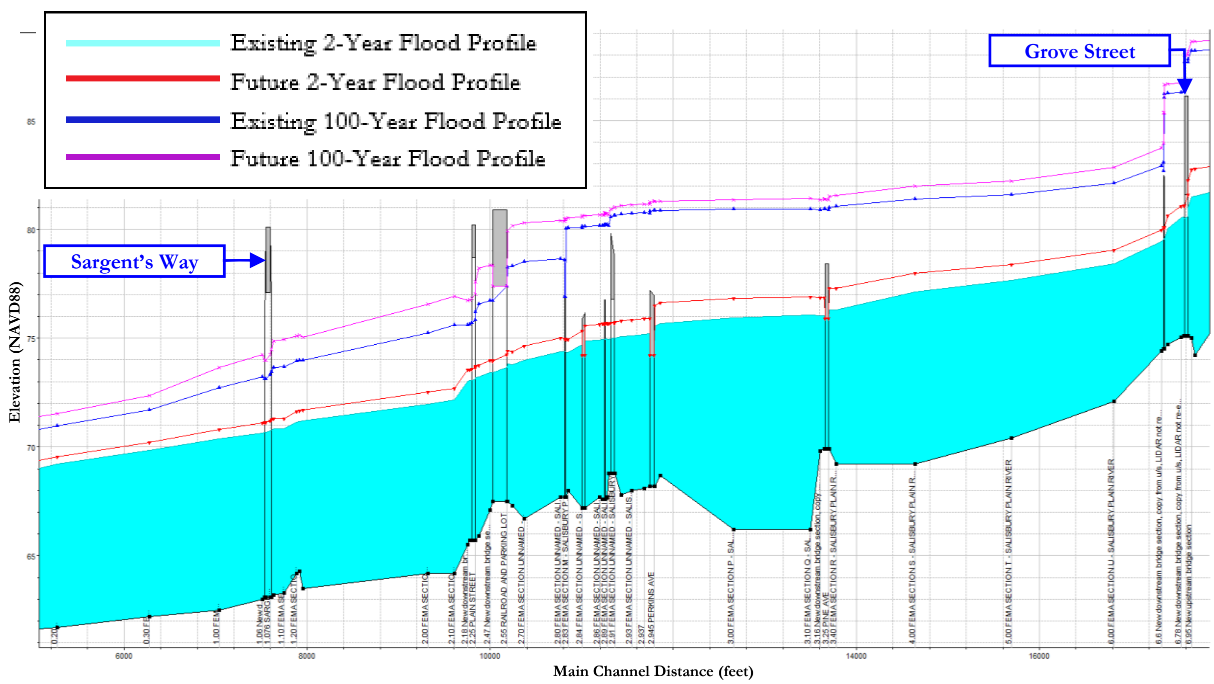

Figure 4-4. Salisbury Plain River Water Surface Profile Comparison between the Existing and Future 2- and 100-Year Flood Events

5 Public Infrastructure & Private Development Risk Assessment

This risk assessment considered both horizontal (roadways, bridges, utilities, etc.) and vertical (buildings) infrastructure. Assessment of horizontal infrastructure was focused on potentially impacted roads and bridges. Vertical infrastructure included all privately or publically owned buildings within mapped flood inundation areas, as determined by modeling results for the 2-year, 100-year, and 500-year floodplains. Vacant parcels within mapped inundation areas were also included in the assessment, in order to assess risks to potential future development.

Utilities infrastructure (e.g., water lines, sewer infrastructure, underground electrical infrastructure) were generally not included in this analysis, as impacts to such underground infrastructure as a result of flooding are less predictable than impacts to surface structures. Utilities impacts also tend to be less localized; that is, whereas flooding at a parcel typically affects the parcel directly (and any associated uses), flooding impacts which interrupt service to an underground utility may have extensive and geographically far-reaching impacts that cannot be adequately predicted or quantified. This assessment did consider pump stations, although at this time there were no pump stations located in modeled floodplain areas within the study area.

Parcels, roads, and bridges were selected for inclusion in the assessment based on proximity to the modeled 2-year, 100-year, and 500-year floodplains, which was determined using GIS analysis. Parcels, bridges, and roads that are either partially or entirely located in the floodplain were included for analysis.

5.1 Data Sources

5.1.1 Inundation Mapping

The GIS shapefiles used for classifying parcel risk according to their location in one of the mapped floodplains were developed using the inundation areas of the 2-year, 100-year, and 500-year floodplains as predicted by Fuss & O'Neill's hydrologic and hydraulic model of Salisbury Brook and Salisbury Plain River within the City of Brockton (developed for Task 2.2 of the City's FY19 MVP Action Grant project:). A description of the methodology and results of this modeling can be found in the report titled, "Hydrologic/Hydraulic Analysis of Salisbury Brook and Salisbury Plain River" (Fuss & O'Neill, January 2020).

5.1.2 Parcel Data

Modeled inundation mapping was used in conjunction with parcel data for the City of Brockton to gather information used to categorize flooding risk for properties in the City. Brockton tax parcel data from August 2019 was obtained from MassGIS. The parcel data includes information on parcel owner, FY19 Tax Assessor's value (including building and land values), building square footage, and lot size.

5.1.3 Road & Bridge Data

Road data was obtained from the official state-maintained MassDOT "Roads" data layer, downloaded from MassGIS. The road data includes AADT (average annual daily traffic), road type, and from- and to-street information (where the street begins and ends). Bridge data was obtained from the MassDOT "Bridges" layer, which includes state-wide bridge data from the Bridge Inspection Management System (BIMS). This data includes bridge location, type, and ownership.

5.1.4 Aerial Imagery

Two sets of aerial imagery—2013/2014 USGS orthoimagery and aerial imagery from the ESRI base map service[6]—were used during GIS analysis to determine which part of each parcel is located within the floodplain, and therefore which portion of the parcel may be at risk of impacts from flooding. The 2013/2014 USGS orthoimagery was used as the primary imagery for classifying parcels, as it provides "leaf-off" imagery (without leaf cover), which allowed for a clearer view of the contents of each parcel. If the portion of the parcel within the 2-year, 100-year, or 500,-year floodplain could not be determined with the USGS imagery, the ESRI base map was used (this imagery is "leaf-on"— thus, while it provided an alternate aerial view of the parcels, it was not ideal for classification due to leaf cover potentially obscuring the contents of the parcels). Additionally, Google Earth aerial and street view were used, when necessary, to determine the contents and/or names of businesses or facilities for each parcel. Bridge length was also estimated from aerial imagery in ArcGIS.

5.2 Categorization Process – Parcels

5.2.1 Criticality of Infrastructure/Property

All parcels were evaluated and categorized based on their 'criticality'. The Federal Emergency Management Agency (FEMA) defines critical facilities as those "activities and facilities for which even a slight chance of flooding is too great a threat." This distinction is based on the critical role that such facilities play in maintaining basic functions or providing emergency response. Critical facilities therefore typically include hospitals, fire and police stations, storage of critical records, and other operations vital to public health and safety.

This assessment sought to explicitly define four categories for the purposes of describing the level of criticality or non-criticality of uses occurring in each potentially impacted parcel:

- Operations – includes infrastructure and facilities considered necessary to maintain day-to-day operational services without which the City could not function, such as Fire and Police facilities, facilities related to utility distribution (water department, DPW, etc.), key communications facilities, etc.

[6] ESRI base map service layer credits: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

- Emergency Community Support – includes facilities that have an important day-to-day value within the City, but serve an elevated role of providing necessary community support functions during emergencies and hazard events. These include essential services such as medical facilities, grocery stores, gas stations, pharmacies, banks, etc. (To contextualize this cluster in current events, think of these as facilities that need to stay open during a public health crisis, such as that currently being experienced with COVID-19).

- Everyday Community Support – includes facilities that provide valuable community resources for connection, gathering, education, etc., but which are not considered "essential" during a crisis event: schools, churches, daycares, community centers, etc. (To continue the COVID-19 example, these are facilities where a shutdown likely causes significant disruption to everyday life for a segment of the community, but does not directly risk public health or safety.)

- Non-Critical – includes infrastructure and property which serve individual/family interests rather than collective interests and/or enhance community life or the economy outside of sectors considered 'essential,' such as residences and retail stores.

Land use codes (codes that classify a parcel's primary use—e.g., residential, commercial, industrial, etc.) were included in the MassGIS parcel data for the City. These land use codes were used to first identify residential parcels, which accounted for approximately two-thirds of parcels impacted by the floodplains. These residential parcels were all classified as "non-critical." Land use codes also provide information on the subsector of each parcel (e.g., parcels can be classified as a "Church, Mosque, Synagogue, Temple, etc.," "Educational Properties," "Museums," etc.) This information was used in conjunction with Google Earth street view to identify the use of the remaining one-third of parcels and assign them a criticality category accordingly.

5.2.2 Economic Development Impacts

In order to capture potential impacts to economic development and jobs, all properties were evaluated and categorized based on two indicators of the economic value or wage generation associated with employment within the City: employee skill level and employer size. These two indicators were used in conjunction, coupling presumed wage levels from the employee skill level categorization with information on employer size (i.e. number of people employed at a location) to create an overall picture of projected wage generation at each location. For example, a large business employing more than 15 individuals at unskilled labor wages might generate wages equivalent to or higher than those generated by a professional level business with only a few highly paid staff.

- Employee Skill Level – Properties were categorized based on the assumption that wages are roughly related to the skill level associated with different types of work. Note that many businesses employ workers at a variety of wage and skill levels (e.g., a manufacturing business may employ unskilled labor for assembly line workers, tradespeople, and professional-level management staff)—for the purposes of this analysis, the employee skill level categorization is intended to capture the wage and skill level of the majority of workers assumed to be employed at a particular location based on the limited information publically available about the business and conditions assumed to be typical of various categories of business.

Land use codes contained in the parcel data include subsector information for all parcels classified as "commercial" or "industrial" (for example, parcels are classified as auto-repair facilities, bank buildings, day cares, etc.). This information was verified using Google Earth street view to confirm the type of establishment on each parcel. Professional judgement was used to assign an Employee Skill Level to the establishment on each parcel based on its industry. For instances with multiple businesses with varying skill levels on the same parcel, the Employee Skill Level was assigned based on the business with the highest ranking skill level (e.g., if a doctor's office and a retail store were on the same parcel, the Employee Skill Level would be assigned to the parcel based on the skill level of the doctor's office).

- Unskilled – this category is intended to capture businesses at the lowest paid labor category, and includes businesses assumed to employ jobs that do not require specific skills and pay minimum-wage, including those businesses identified as gas stations, fast food and dine-in restaurants, etc. For the purposes of this assessment, parcels which were assumed to have no business operations (based on their categorization as "residential" in the Tax Assessor's land use codes) were also included in this category, based on the assumption that such parcels have some inherent unskilled labor involved in upkeep and management.

- Trade – this category was assigned to businesses assumed to employ a majority of its staff as skilled laborers or trade laborers, as well as those occupations requiring licensure without an accompanying professional or advanced degree, or other labor anticipated to be in a similar wage range. The category therefore includes construction and/or trade-based companies (e.g., electrical, plumbing, HVAC companies, auto mechanics, etc.), real estate offices, insurance firms, and similar businesses.

- Professional – this category is intended to capture businesses where employees typically receive relatively higher wages associated with completion of professional or advanced degrees. Schools and universities, medical facilities, law offices, etc. are included in this labor category.

- Employer Size – This indicator reflects the number of people anticipated to be employed at a given business, and therefore helps to predict not only the total dollar value of wages generated at a given location, but also the number of employees who could potentially be impacted by flooding at the business location. Numbers of employees referenced below are meant to entail the number of individuals required to fully staff the business at any given time, not necessarily the number of employees on the payroll. For example, a restaurant may have more than 15 employees, many of whom work part-time, but the restaurant is considered fully staffed with 10 people on the premises.

  Employer Size was assigned to each parcel based on evaluation of its land use code and a visual assessment using Google Earth. Preliminarily, land use codes were used to identify the industry for each parcel, which provided a baseline on the average employment size (e.g., fast-food restaurants were assumed on average to employs approximately 15 people[7]). Visual assessment

[7] https://www.statista.com/statistics/196672/employees-per-establishment-in-us-fast-food-restauants-since-2002/

using Google Earth street view was also used to confirm these assumptions and refine them based on the physical size of each establishment.

- No Employees/Non-Business – For the purposes of this assessment, parcels which were assumed to have no business operations (based on their categorization as "residential" in the Tax Assessor's land use codes) were assigned to the no employees/non-business category. Note that some residential locations do generate wage income via self-employed business activity, home-based medical or support staff, etc.; similarly, residences also frequently generate significant unpaid labor in the form of caretaking activities and other household labor. These activities cannot be captured at the scale of this analysis.

- Small Business – this category includes businesses assumed to function with less than 15 individuals.

- Multiple Small Businesses in Single Parcel – because this analysis relies on parcel-level data, this category was developed to capture locations where multiple small businesses exist within a single parcel, e.g., a strip mall or a professional office building that houses multiple doctors' offices.

- Large Business – this category includes businesses assumed to require more than 15 individuals to function.

5.2.3 Housing Impacts

All properties were evaluated and categorized to quantify their value in providing housing for City residents, and thereby capture the potential for flooding to impact housing stock and housing provision. Specifically, this category considers how many families may be impacted by flooding at a particular property. The precision of this analysis is limited by the fact that accurate information about the number of residents actively residing at a particular location is not available, some residences may be vacant, and household sizes vary widely. This analysis therefore utilizes available parcel data related to housing capacity to quantify the maximum number of households potentially impacted at a given location. Land use codes from the Tax Assessor's database classify residential parcels as single-family, two-family, and three-family; apartments are classified as either four to eight units or more than eight units. These codes were then used to classify residential parcels under one of the following categories:

- No Housing Value (non-residential parcels)
- Single Family
- Two Family
- Three Family
- Four to Eight Families
- Nine or More Families

5.2.4 Potential for Direct Financial Damages

The City of Brockton Assessor's database was used to determine the total FY19 tax value of each parcel (including land and building value). This value was used as a proxy for the potential direct financial damages that might be incurred in a flooding event that results in property damage or loss. Note that some parcels are currently undeveloped. Inclusion of the land value for such parcels is useful in understanding how flood impacts could dampen future economic development in addition to how flooding may impact structures already located within flood-prone areas.

In addition to the raw tax value, each parcel was assigned to a category based on the following ranges, which were defined based on quintiles of the data to produce an even distribution such that 20% of properties fall into each category:

- Up to $167,300
- $167,301 to $226,060
- $226,061 to $266,660
- $266,661 to $334,880
- $334,881+

5.3 Categorization Process – Roads & Bridges

5.3.1 Traffic Count

For roads and bridges, traffic count—that is, how heavily used the roadway is on an average day—was used as a proxy for criticality. Two methods were considered for categorizing roadway usage: average annual daily traffic (AADT) counts from MassDOT and road class (highway/major road/minor road) data. We determined that AADT provides greater nuance in understanding how frequently a roadway is traveled, and therefore is likely to serve as a better indicator of the potential disruption from flooding of a road segment or bridge that leads to a road closure.

All roads in the City were evaluated for vulnerability to inundation based on their location with respect to the 2-year, 100-year, and 500-year modeled floodplains. For segments located partially or wholly within any of three modeled inundation areas, AADT was used to assign the segment to one of the following categories. Each bridge within one of the inundation areas was also assigned a value based on the AADT for the road segment within which it is located.

- Up to 2,500 vehicles per day
- 2,501 to 5,000 vehicles per day
- 5,001 to 10,000 vehicles per day
- 10,001 to 20,000 vehicles per day
- 20,000+ vehicles per day

5.3.2 Geographic Extent of Impacts

Because the roadways in Brockton's downtown area are loosely based on a grid system, most locations can be reached from multiple routes, and the likelihood of flooding entirely cutting off an area is relatively low. Extent of impacts was therefore characterized by developing categories that describe the length of a road segment that would be inundated during a flooding event. The maximum segment inundation length was roughly 1100 feet. Categories were thus developed to roughly reflect the number of City block units (or partial units) that would be impacted (though the system is not strictly uniform, typical City block lengths in Brockton are generally about 250-300 feet for short blocks, and approximately either 500 or 1000 feet for long blocks). Bridges were categorized based on the total length of the bridge; note that all bridges are within one of the lowest two impact categories.

- 0 to 50 linear feet located in modeled floodplain
- 51 to 250 linear feet located in modeled floodplain
- 251 to 500 linear feet located in modeled floodplain
- 501 to 1,000+ linear feet located in modeled floodplain

5.3.3 Bridge Presence

Overtopped bridges can become acute failure points, particularly if there are underlying structural condition problems or geomorphic risk factors (such as an entry angle that encourages accumulation of debris at the structure inlet). To capture this additional element of risk, each road segment was assigned a categorical variable based on the presence or absence of a bridge within the segment. All bridges were assigned to the bridge present category.

- No bridge within road segment
- Bridge/road-stream crossing within road segment

5.4 Findings

5.4.1 Parcel Analysis

A total of 1,230 parcels were identified within the modeled 2-year, 100-year, or 500-year floodplains (407 in the 2-year floodplain, 525 in the 100-year floodplain, and an additional 298 in the 500-year floodplain). Categorization results for all residential and non-residential parcels are available in **Appendix B**.

Of the parcels in the 2, 100, and 500-year floodplains, 95% were identified as non-critical, 3% as everyday community support infrastructure, 1% as emergency community support infrastructure, and 1% as operations (**Map A**). Residential parcels account for the majority (65%) of all parcels, while vacant properties/land and miscellaneous parcels accounts for the next highest category of parcels at 23%. Retail and service establishments account for 8% of parcels, community centers and schools for 3%, and operations, gas stations, and medical facilities for the remaining 1% (**Figure 5-1).**

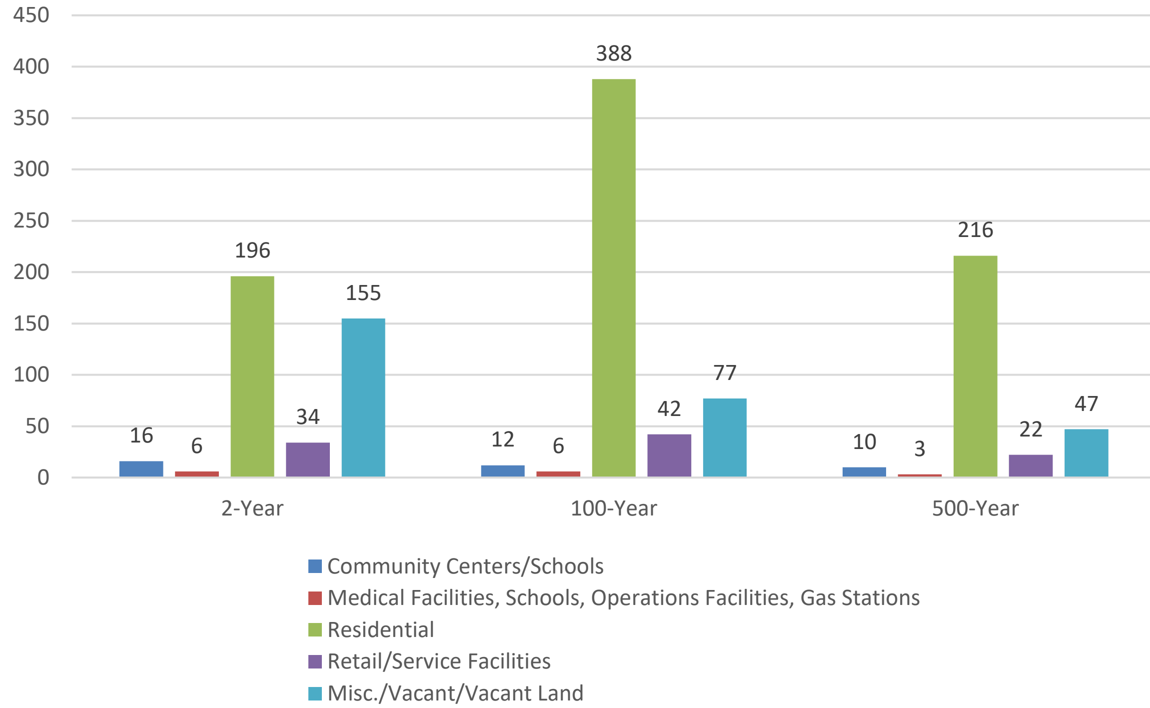

Figure 5-1. Distribution of parcel use in the modeled 2-year, 100-year, and 500-year floodplains

In terms of Employer Size, 89% of parcels in the three modeled floodplains were categorized as having no employees/being a non-business parcel, while 6% are classified as small businesses. One percent (1%) of parcels are classified as having multiple small businesses on the same property, and 4% of parcels are classified as large businesses (**Map B; Figure 5-2**). For Employee Skill Level, 91% of parcels are classified as "unskilled" (which includes parcels that are classified as having no employment value), 6% are classified as "trade," and 3% are classified as "professional" (**Map C**; **Figure 5-3).**

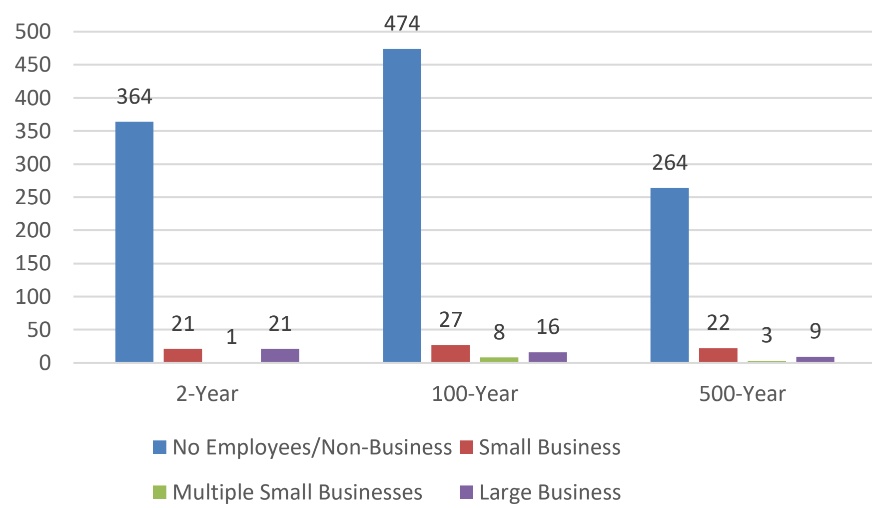

Figure 5-2. Distribution of Employer Size categories across parcels in the modeled 2-year, 100-year, and 500-year floodplains

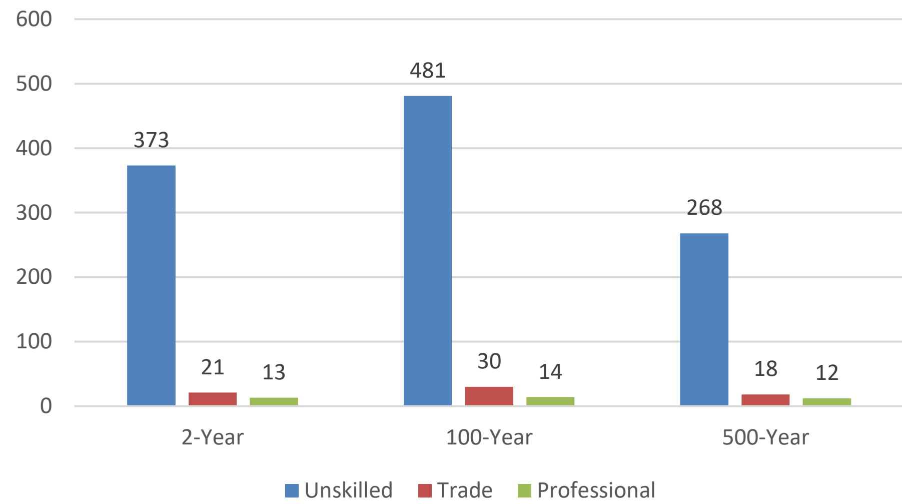

Figure 5-3. Distribution of Employee Skill Level across parcels in the modeled 2-year, 100-year, and 500-year floodplains

Thirty-five percent (35%) of parcels in the three modeled floodplains have no housing capacity (non-residential parcels), while 39% are classified as single-family, 11% as two-family, 11% as three-family, 2% as four to eight family, and 2% as residences for more than eight families (**Map D; Figure 5-4).**

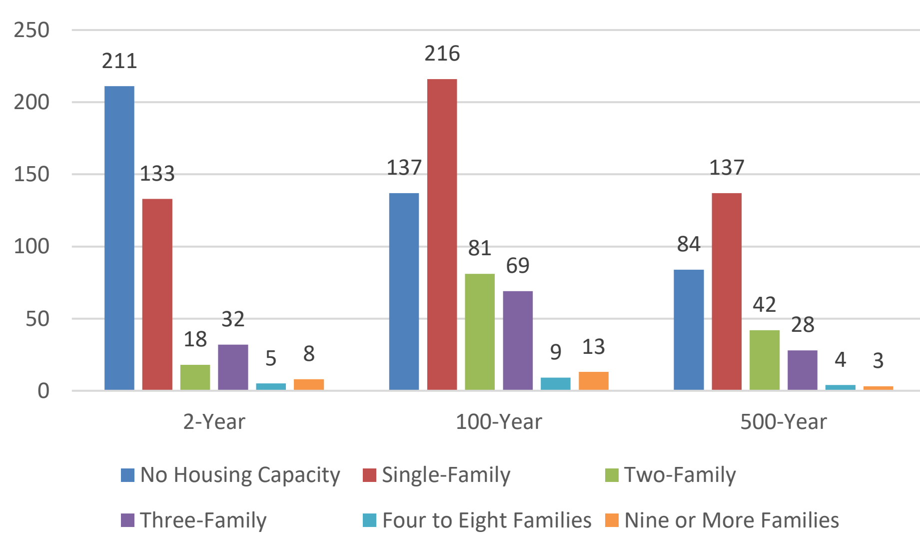

Figure 5-4. Distribution of housing capacity across parcels in the modeled 2-year, 100-year, and 500-year floodplains

The average total property value for parcels in the three modeled floodplains is approximately $399,000. The average residential property value is $228,000 for a single-family property, while the median property value is $242,000. The average property value is $292,000 for a two-family property, with a median value of $250,000. For a three-family property, the average property value is $343,000, with a median property value of $262,000 (**Figure 5).** The average property value for parcels classified as small businesses is $523,000, (median value of $262,000) while the average property value for parcels classified as having multiple small businesses is $1.38 million (median value of $275,000). The average property value for parcels classified as large businesses is $1.64 million (median value of $283,000) (**Figure 5-6**). **Map E** illustrates direct financial damages for all parcels in the modeled floodplains.

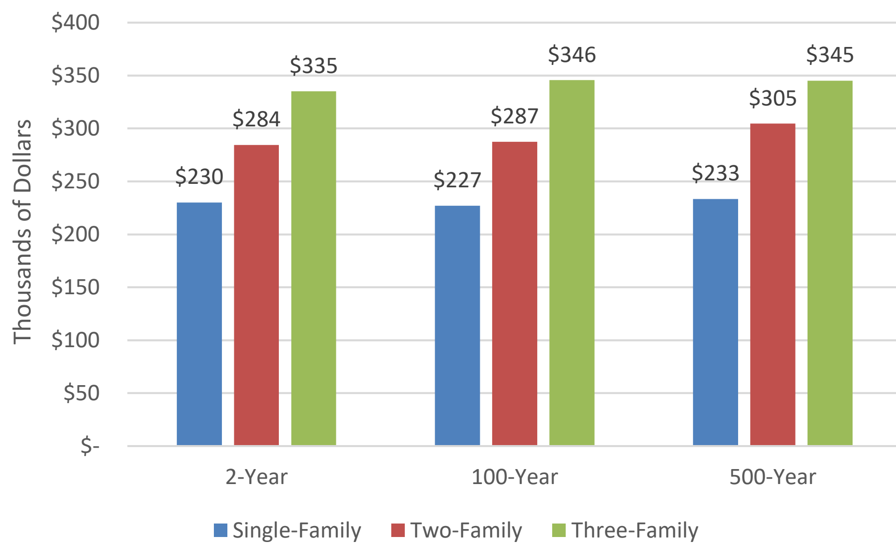

Figure 5-5. Average prices for single-family, two-family, and three-family home parcels in the modeled 2-year, 100-year, and 500-year floodplains (in thousands of dollars)

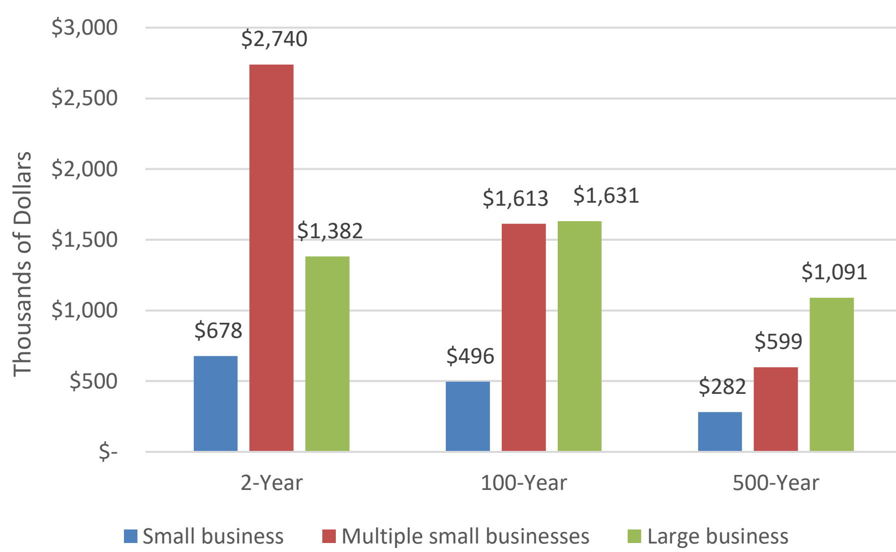

Figure 5-6. Average prices for business parcels in the modeled 2-year, 100-year, and 500-year floodplains (in thousands of dollars)

In terms of emergency response infrastructure, no police stations are located within the modeled 2, 100, or 500-year floodplain. One fire station (Brockton Fire Department Station #4) is located within the 100-year floodplain. Additional municipal properties impacted by the modeled inundation areas include the Brockton Water Department, the Council on Aging, the Parks Department, the School Department, and the Library Foundation. **Table 5-1** lists the details of municipal properties impacted by the 2, 100, or 500-year floodplain.

Table 5-1. Municipal properties in the Modeled 2, 100, or 500-year floodplain in Brockton, MA

Facility	Portion of Parcel Impacted	Flooding Annual Recurrence
Brockton Water Department	Undeveloped portion	2-year
Council on Aging	Access to building/parking (based on planned expansion)	2-year
Brockton Fire Department Station #4	Undeveloped portion	100-year
Brockton Parks Department	Undeveloped portion	100-year
Brockton School Department/David E. Crosby Administrative Building	Access to building/parking	500-year
Brockton Library Foundation	Building	500-year

Additionally, there are six schools/nurseries that are located within the modeled 2-year, 100-year, and 500-year floodplains, as listed in **Table 5-2**. Three schools are located within the 2-year floodplain, two are located within the 100-year floodplain, and one is located within the 500-year floodplain.

Table 5-2. Municipal properties in the 2, 100, or 500-year floodplain in Brockton, MA

School	Portion of Parcel Impacted	Flooding Annual Recurrence
Brockton Day Nursery	Undeveloped portion	2-year
Brocton Community Schools Adult Learning Center	Undeveloped portion	2-year
Gilmore Early Childhood Education Center	Undeveloped portion	2-year
Champion High School at the Keith Center/Frederick Douglass Academy	Undeveloped portion	100-year
New Heights Charter School	Access to building/parking	100-year
Arnone Elementary School	Undeveloped portion	500-year

5.4.2 Bridge & Road Risk Analysis

A total of 19 bridges are located in the predicted inundation areas and projected to experience potential overtopping: 17 in the 100-year floodplain and two in the 500-year floodplain. **Table 5-3** includes location and ownership information on these bridges, as well as the names of associated roads and waterbodies. Six of these bridges are longer than 50 feet, while 13 are shorter than 50 feet.

There are 171 road segments that are located in the modeled 2-year, 100-year, and 500-year floodplain. **Appendix B** contains information on street name, road type, from- and to-street information (where the street begins and ends), and AADT (average annual daily traffic, obtained from MassDOT) for all 171 road segments. The same road can appear several times on this list if multiple segments of the road (as defined by the MassDOT data) are impacted by the floodplain. Of these 171 road segments, 17 are inundated within the 2-year floodplain, an additional 111 are inundated within the 100-year floodplain, and an additional 43 are within only the 500-year floodplain. Fourteen (14) of the impacted roads are numbered routes (including Routes 27, 28, and 123), 11 are major roads, and 146 are minor streets or roads.

Table 5-3. Bridges in the 2, 100, and 500-year floodplains in Brockton, MA

Street Name	Waterbody	Ownership	Flooding Annual Recurrence	Traffic Count (AADT)	Geographic Extent of Impacts Category
Main St	Salisbury Brook	Municipal	100-Year	10,001 to 20,000 vehicles per day	51 to 250 linear feet
Carleton St	Salisbury Brook	Municipal	100-Year	Up to 2,500 vehicles per day	51 to 250 linear feet
Forest St	Salisbury Plain River	Municipal	100-Year	Up to 2,500 vehicles per day	51 to 250 linear feet
North Arlington St/ Newbury St	Salisbury Brook	Municipal	100-Year	Up to 2,500 vehicles per day	51 to 250 linear feet
Pine Ave	Salisbury Plain River	Municipal	100-Year	Up to 2,500 vehicles per day	51 to 250 linear feet
Pleasant St	Salisbury Brook	Municipal	100-Year	20,000+ vehicles	0 to 50 linear feet
Grove St	Salisbury Brook	Municipal	100-Year	10,001 to 20,000 vehicles per day	0 to 50 linear feet
Warren Ave	Salisbury Brook	Municipal	100-Year	5,001 to 10,000 vehicles per day	0 to 50 linear feet
Ash St	Salisbury Brook	Municipal	500-Year	2,501 to 5,000 vehicles per day	0 to 50 linear feet
Prospect St	Salisbury Brook	Municipal	100-Year	2,501 to 5,000 vehicles per day	0 to 50 linear feet
Moraine St	Salisbury Brook	Municipal	500-Year	Up to 2,500 vehicles per day	0 to 50 linear feet
Allen St	Salisbury Brook	Municipal	100-Year	Up to 2,500 vehicles per day	0 to 50 linear feet
Bartlett St	Salisbury Brook	Municipal	100-Year	Up to 2,500 vehicles per day	0 to 50 linear feet
Otis St	Salisbury Brook	Municipal	100-Year	Up to 2,500 vehicles per day	0 to 50 linear feet
Perkins St	Salisbury Brook	Municipal	100-Year	Up to 2,500 vehicles per day	0 to 50 linear feet
Spring St	Salisbury Brook	Municipal	100-Year	Up to 2,500 vehicles per day	0 to 50 linear feet
White Ave	Salisbury Brook	Municipal	100-Year	Up to 2,500 vehicles per day	0 to 50 linear feet

Six road segments have an AADT of more than 20,000, seven streets have 10,000 to 20,000, 12 streets have 5,000 to 10,000, 21 have 2,500 to 5,000, and 125 have up to 2,500 vehicles (**Map F**).

The length of road impacted by the floodplain varies from an estimated two feet to just over 1,100 feet, with an average of 195 feet and a median of 147 feet. The average length of road impacted by the 2-year flood is 102 feet, while it is 227 feet for the 100-year flood, and 152 feet for the 500-year flood.

Table 5-4 includes information on impacted roads, including street name, road type, and AADT (average annual daily traffic, obtained from MassDOT) for all streets with an AADT higher than 5,000.

Table 5-4. Road Segment Categorization for Segments with AADT> 5,000 in Brockton, MA

Street Name	Route Segment ID (MassDOT)	Road Segment ID (MassDOT)	Route Number	Road Class	Flooding Annual Recurrence	Geographic Extent of Impacts	Bridge Presence	Traffic Count (AADT)
Pleasant Street	SR27 NB	78772	27	Other numbered route	100-Year	51 to 250 linear feet	No	20,000+ vehicles
Pleasant Street	SR27 NB	78774	27	Other numbered route	100-Year	51 to 250 linear feet	No	20,000+ vehicles
Pleasant Street	SR27 NB	78768	27	Other numbered route	500-Year	251 to 500 linear feet	No	20,000+ vehicles
Pleasant Street	SR27 NB	78767	27	Other numbered route	500-Year	51 to 250 linear feet	No	20,000+ vehicles
Pleasant Street	SR27 NB	78770	27	Other numbered route	500-Year	0 to 50 linear feet	No	20,000+ vehicles
Pleasant Street	SR27 NB	78765	27	Other numbered route	500-Year	0 to 50 linear feet	No	20,000+ vehicles
Main Street	N4636 NB	74894		Major road - arterials and collectors	100-Year	251 to 500 linear feet	Yes	10,001 to 20,000 vehicles
Summer Street	N4706 NB	76773		Minor street or road	100-Year	51 to 250 linear feet	No	10,001 to 20,000 vehicles
Grove Street	N4635 NB	75658		Major road - arterials and collectors	100-Year	51 to 250 linear feet	No	10,001 to 20,000 vehicles
Main Street	SR28 NB	75462	28	Other numbered route	100-Year	0 to 50 linear feet	No	10,001 to 20,000 vehicles
Main Street	SR28 NB	75483	28	Other numbered route	100-Year	0 to 50 linear feet	No	10,001 to 20,000 vehicles
Main Street	N4636 NB	74873		Major road - arterials and collectors	100-Year	0 to 50 linear feet	No	10,001 to 20,000 vehicles
Main Street	N4636 NB	74911		Major road - arterials and collectors	500-Year	51 to 250 linear feet	No	10,001 to 20,000 vehicles
Warren Avenue	N4638 NB	77028		Major road - arterials and collectors	100-Year	251 to 500 linear feet	No	5,001 to 10,000 vehicles
Brookside Avenue	N4621 NB	75475		Major road - arterials and collectors	100-Year	251 to 500 linear feet	No	5,001 to 10,000 vehicles
Brookside Avenue	N4621 NB	75469		Major road - arterials and collectors	100-Year	51 to 250 linear feet	No	5,001 to 10,000 vehicles
Warren Avenue	N4638 NB	74897		Major road - arterials and collectors	100-Year	51 to 250 linear feet	No	5,001 to 10,000 vehicles
Crescent Street	SR123 EB	77765	123	Other numbered route	100-Year	51 to 250 linear feet	No	5,001 to 10,000 vehicles
Belair Street	N4617 NB	74551		Major road - arterials and collectors	100-Year	51 to 250 linear feet	No	5,001 to 10,000 vehicles
Montello Street	SR28 NB	77069	28	Other numbered route	500-Year	251 to 500 linear feet	No	5,001 to 10,000 vehicles
Montello Street	SR28 NB	74845	28	Other numbered route	500-Year	51 to 250 linear feet	No	5,001 to 10,000 vehicles
Montello Street	SR28 NB	74845	28	Other numbered route	500-Year	51 to 250 linear feet	No	5,001 to 10,000 vehicles
Plain Street	N4653 EB	77589		Major road - arterials and collectors	500-Year	51 to 250 linear feet	No	5,001 to 10,000 vehicles
Montello Street	SR28 NB	74845	28	Other numbered route	500-Year	0 to 50 linear feet	Yes	5,001 to 10,000 vehicles
Montello Street	SR28 NB	74909	28	Other numbered route	500-Year	0 to 50 linear feet	No	5,001 to 10,000 vehicles

6 Prioritization of Flood Risks

6.1 Data Sources

6.1.1 Inundation Mapping

The GIS shapefiles used for parcel floodplain classification were developed using the inundation areas of the 2-year, 100-year, and 500-year floodplains as predicted by Fuss & O'Neill's hydrologic and hydraulic model of Salisbury Brook and Salisbury Plain River within the City of Brockton (developed for Task 2 of the City's FY19 MVP Action Grant project:). A description of the methodology and output of this modeling can be found in the report titled, "Hydrologic/Hydraulic Analysis of Salisbury Brook and Salisbury Plain River" (Fuss & O'Neill, January 2020).

6.1.2 Categorization Data

Categorization of property and infrastructure was completed as part of Task 3 of the City's FY19 MVP Action Grant. That process assessed the potential impact of flooding at parcels/property and road and bridge infrastructure within mapped inundation areas. Properties were analyzed and categorized based on factors of criticality, economic development impacts, housing impacts, and potential for direct financial damages. Roads and bridges were categorized based on their relative importance for travel through the City (indicated by traffic counts), the length of impacted roadway, and whether or not there was a bridge crossing on the road segment (a potential failure point). The details of the categorization process are presented in the technical memorandum for Task 3, "Public Infrastructure and Private Development Risk Assessment."

6.2 Prioritization Tool Metrics

Fuss & O'Neill developed a prioritization tool that utilizes a weighted scoring method to prioritize property/parcels and road/bridge infrastructure in the floodplain based on probability of impacts (expected flood frequency) and the magnitude of those impacts, which was in turn defined using the categorization data generated in Task 3. This methodology is built on the risk identification and evaluation framework outlined by the U.S. Environmental Protection Agency's "Being Prepared for Climate Change: A Workbook for Developing Risk-Based Adaptation Plans" (EPA August 2014).

The prioritization tool is built around the following basic definition of risk:

Flooding Risk = Probability of Flooding * Magnitude of the Impact of Flooding

6.2.1 Risk Scores – Parcels

Table 6-1 summarizes the factors used in the prioritization tool to convert categorization data into a scoring system for developing overall parcel risk scores.

Table 6-1. Description of Parcel Prioritization Factors

Factor	Factor Description
Flooding Probability	A score was assigned to each parcel based on the modeled floodplain area for the most frequent flood recurrence interval that it falls within (e.g., if a parcel was in both the 2- and 100- year floodplain, it was classified for the 2- year). This score represents the annual average probability of flooding for a given parcel. **1** Located in 500-year floodplain **2** Located in 100-year floodplain **3** Located in 2-year floodplain
Property Use within Floodplain Weight	A score was assigned based on the land uses that could be observed to occur within the portion of the parcel that falls within the modeled floodplain area. Where a parcel was located across more than one floodplain, the score was assigned based on land uses within the area affected by the most frequent flood recurrence interval. This score gives less weight to impacted parcels that do not contain structures, as shown: **0.25** Only undeveloped land in floodplain **0.50** Access to parking/building impacted (i.e. driveways, parking lots, but not buildings) **1.00** All or part of a building/structure is located in the inundation zone
Criticality Weight*	A score was assigned to each parcel based on the criticality of its function and its purpose within the community. This score gives decreasing weight to impacts associated with parcels with lower criticality. **0.25** Non-critical (many retail facilities, residences, etc.) **0.50** Everyday Community Support Infrastructure (churches, community center, schools, YMCA, etc) **0.75** Emergency Community Support Infrastructure (Gas stations, grocery stores, pharmacies, etc.) **1.00** Operations (Police, Fire, etc.)
Employee Skill Level Metric*	The Employee Skill Level metric was assigned to each parcel based on its employee skill classification, as one indicator of economic value/wage generation: **1** Unskilled or non-business parcel **2** Trade (training/specialization or licensure required) **3** Professional (professional or advanced degree required)
Economic Development Impacts Metric**	The Employer Size metric was assigned to each parcel based on its business size classification, as a second indicator of economic value/wage generation: **1** No Employees/Non-Business **2** Small Business **3** Multiple Small Businesses in Single Parcel **4** Large business
Housing Capacity Metric*	A score was assigned to each parcel based on its land use classification in the Brockton Tax Assessor's database. **0** No Housing Value (non-residential parcels) **1** Single-Family Residential **2** Two-Family Residential **3** Three-Family Residential **4** Three to Seven-Family Residential **5** Eight+ Family Residential

Potential for Direct Financial Damages Metric*	Each parcel was assigned a score based on the following ranges and the total value of each property (combined building and land values) as listed in the Brockton Tax Assessor's database. **1** $0 to $167,300 **2** $167,301 to $226,060 **3** $226,061 to $266,660 **4** $266,661 to $334,880 **5** $334,881 to $25,783,000

*Details of the categorization definitions for these factors are presented in the technical memorandum for Task 3, "Public Infrastructure and Private Development Risk Assessment"

Using the above factors, the formula below was applied to calculate a risk score for each parcel. In the formula, the probability of flooding is multiplied by key metrics for financial, housing, and employment that are weighted by factors quantifying the type and criticality of property use. Note that all metrics have been normalized to a 0 to 10 scale to account for the fact that different metrics have varying numbers of categories, and therefore differing score ranges.

$$\boldsymbol{R_i} = \boldsymbol{F_i} * (\boldsymbol{U_i} * \boldsymbol{C_i} * \ (\boldsymbol{S_i} + \boldsymbol{E_i} + \boldsymbol{H_i} + \boldsymbol{D_i}))$$

where:

$\boldsymbol{R_i}$ = Risk Score of parcel *i*
$\boldsymbol{F_i}$ = Flooding Probability of parcel *i*
$\boldsymbol{U_i}$ = Property Use within Floodplain weight for parcel *i*
$\boldsymbol{C_i}$ = Criticality weight for parcel *i*
$\boldsymbol{S_i}$ = Employee Skill Level for parcel *i* (normalized to a 0 to 10 scale)
$\boldsymbol{E_i}$ = Economic Development Impacts for parcel *i* (normalized to a 0 to 10 scale)
$\boldsymbol{H_i}$ = Housing Capacity for parcel *i* (normalized to a 0 to 10 scale)
$\boldsymbol{D_i}$ = Potential for Direct Financial Damages for parcel *I* (normalized to a 0 to 10 scale)

6.2.2 Risk Scores – Roads & Bridge Infrastructure

Table 6-2 summarizes the factors used in the prioritization tool to convert categorization data into a scoring system for developing overall road and bridge risk scores.

Table 6-2. Description of Road and Bridge Infrastructure Prioritization Factors

Factor	Factor Description
Flooding Probability	A score was assigned to each road segment or bridge based on the modeled floodplain area for the most frequent flood recurrence interval that it falls within (e.g., if a parcel was in both the 2- and 100-year floodplain, it was classified for the 2 year). This score represents the probability of flooding for a given piece of infrastructure. **1** Located in 500-year floodplain **2** Located in 100-year floodplain **3** Located in 2-year floodplain
Traffic Count Metric	A score was assigned to each road segment or bridge based on its associated traffic count. **1** Up to 2,500 vehicles per day **2** 2,501 to 5,000 vehicles per day **3** 5,001 to 10,000 vehicles per day **4** 10,001 to 20,000 vehicles per day **5** 20,000+ vehicles per day
Geographic Extent of Impacts Metric *	A score was assigned to each road segment or bridge based on the linear distance of roadway located within the mapped inundation zone, or the length of the bridge or road-stream crossing. **1** 0 to 50 linear feet located in inundation zone **2** 51 to 250 linear feet located in inundation zone **3** 251 to 500 linear feet located in inundation zone **4** 501 to 1000+ linear feet located in inundation zone

Using the above factors, the formula below was applied to calculate a risk score for each road segment or bridge. In the formula, the probability of flooding is multiplied by metrics for traffic count and geographic extent of impacts:

$$\boldsymbol{R_i = F_i * (T_i + G_i)}$$

where:
$\boldsymbol{R_i}$ = Risk Score of road segment or bridge i
$\boldsymbol{F_i}$ = Flooding Probability of road segment or bridge i
$\boldsymbol{T_i}$ = Traffic Count of road segment or bridge i (normalized to a 0 to 10 scale)
$\boldsymbol{G_i}$ = Geographic Extent of Impacts Score of road segment or bridge i (normalized to a 0 to 10 scale)

6.3 Scoring Results

6.3.1 Risk Score Results – Parcels

Normalized risk scores range from 0 to 10. Tallied risk scores for all parcels are available in **Appendix B**. Parcels and scoring data for the highest risk parcels are listed below in **Table 6-3.** Locations with the highest risk scores represent those parcels that are individually important to protect. We recommend that prioritization of locations for flood protection (either via nature-based solutions, traditional grey infrastructure approaches such as raising structures or constructing flood walls, or relocating land uses out of the floodplain) also consider areas where risk clusters. Such clusters help to highlight areas of residential or otherwise non-critical use which may not score high individually, but which represent a risk 'hotspot' within the City. **Figures 6-1 to 6-3** provide examples of several of these 'hotspots' in the City. Mapped risk scores are available in **Appendix B**.

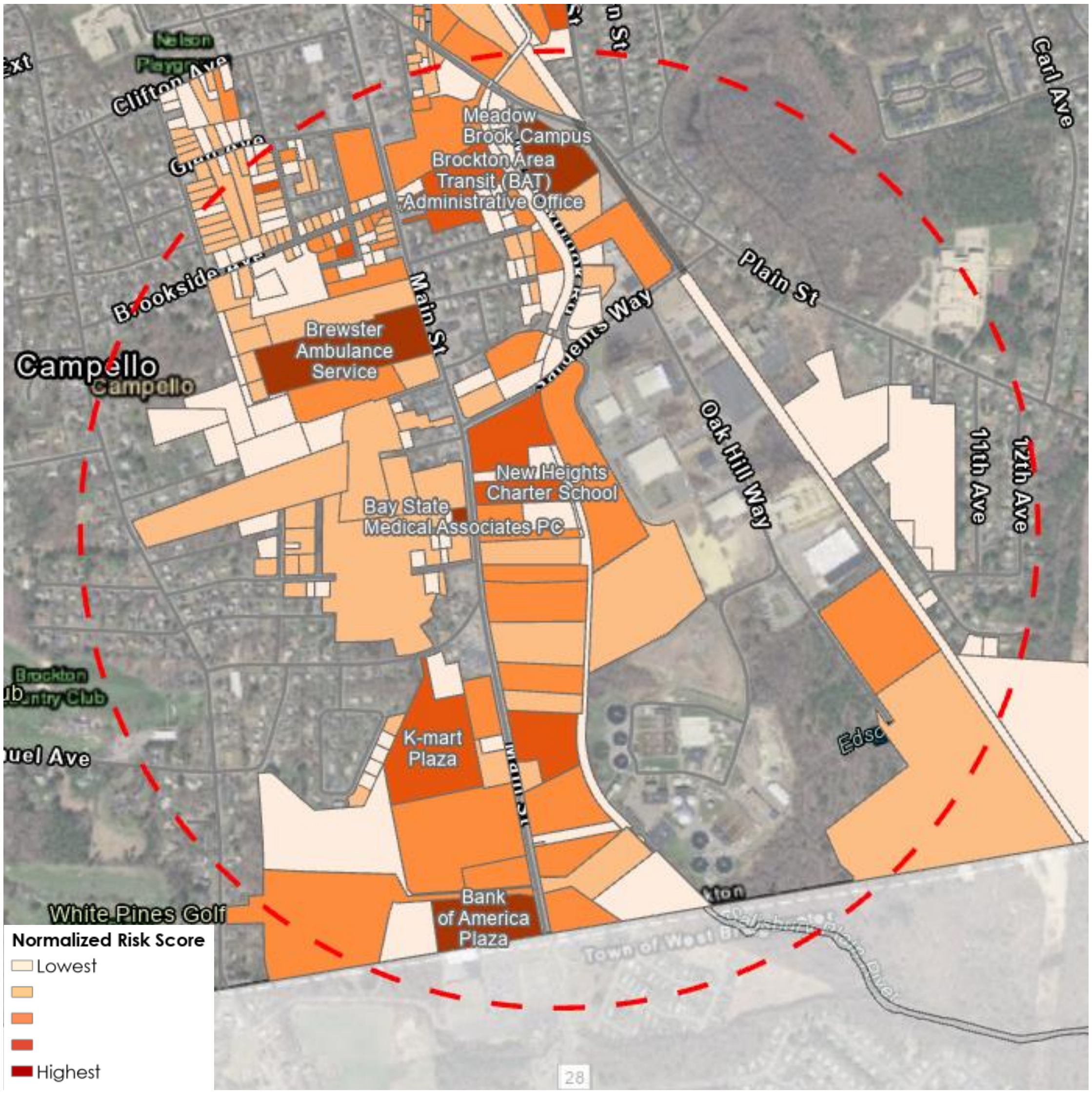

Figure 6-1. Hotspot #1, Meadowbrook Road and Main Street. This hotspot contains the Bank of America Plaza, K-Mart Plaza, Bay State Medical Associates PC, New Heights Charter School, Brewster Ambulance Service, Brockton Area Transit (BAT) Administrative Office), and the Meadow Brook Campus (shaded as dark orange in the above figure).

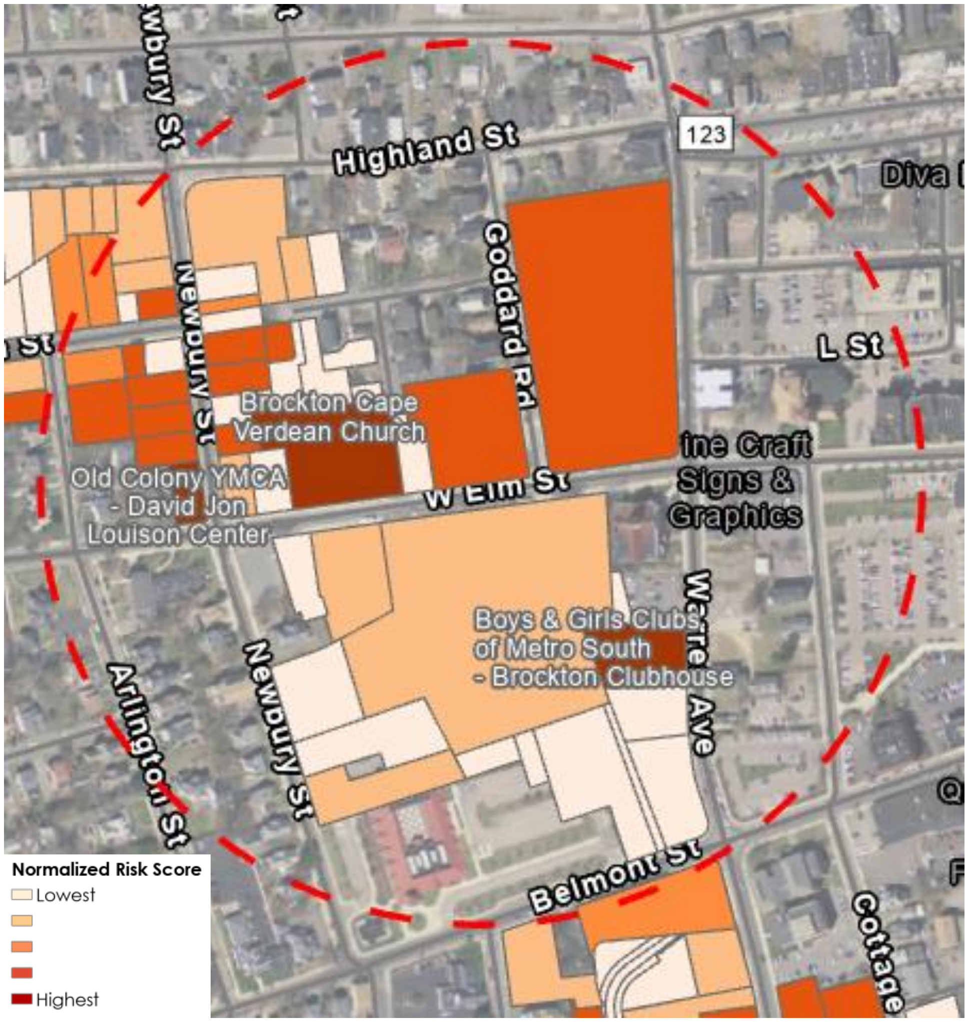

Figure 6-2. Hotspot #2, W Elm Street and Warren Avenue. This hotspot contains the Old Colony YMCA David Jon Louison Center, the Brockton Cape Verdean Church, and the Boys and Girls Club of Metro South—Brockton Clubhouse (shaded as dark orange in the above figure).

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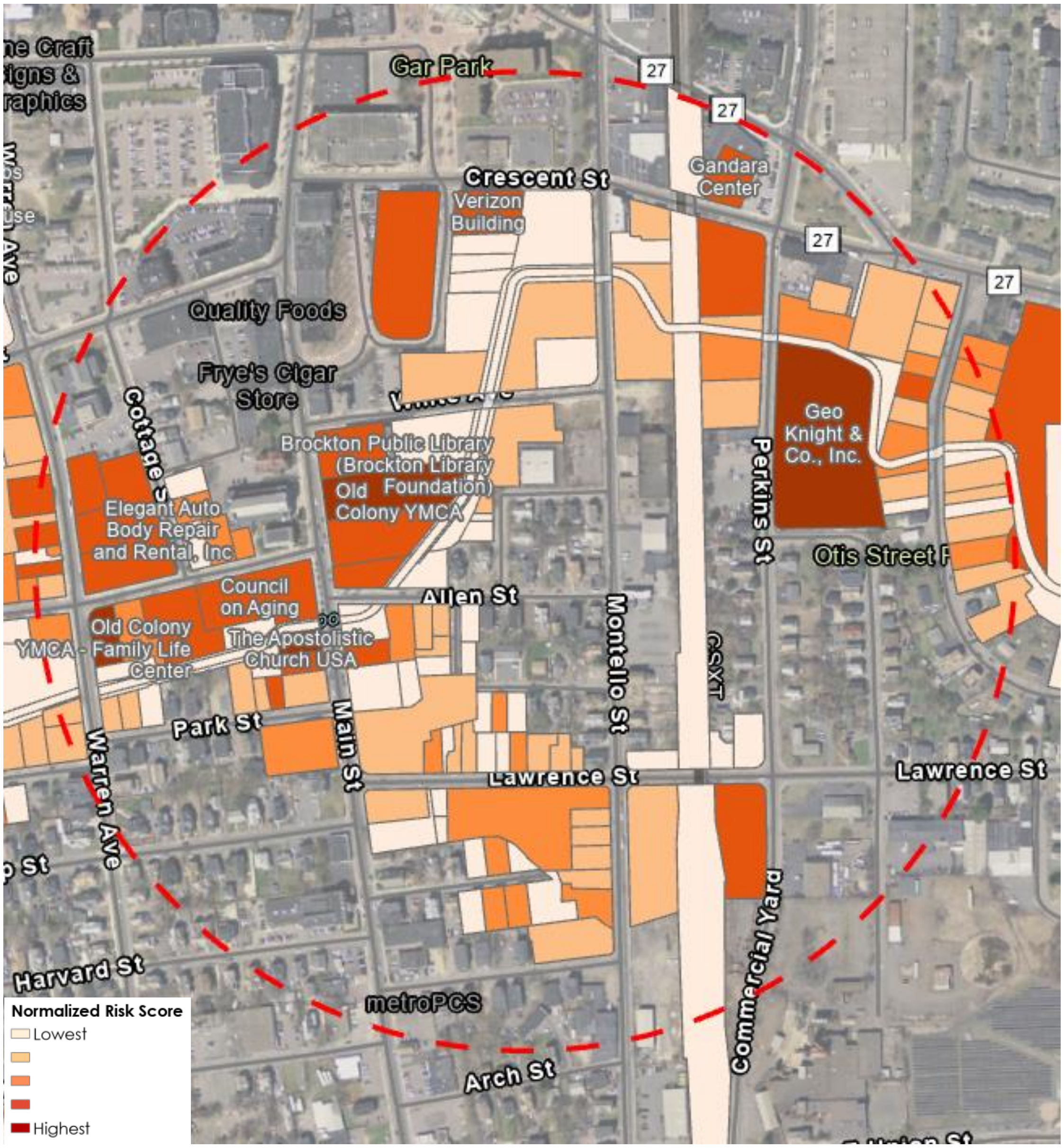

Figure 6-3. Hotspot #3, Warren Avenue, Main Street, Crescent Street, and Perkins Street. This hotspot contains the Old Colony YMCA Family Life Center, the Brockton Public Library, the Old Colony YMCA, the Gandara Center, Geo Knight & Co., Inc., the Verizon Building, and the Brockton Council on Aging (a parking lot expansion is also planned along the Brook) (shaded as dark orange in the above figure).

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Table 6-3. Top 25 parcels with the highest risk scores in Brockton, MA

Map Parcel ID	Parcel Street Address	Parcel Name	Housing Capacity		Economic Development Impact		Employee Skill Level		Potential for Direct Financial Damages		Criticality Weight	Property Use in Floodplain Weight	Flooding Probability	Normalized Risk Score (0-10)
			Scale (0-5)	Normalized Scale (0-10)	Scale (1-4)	Normalized Scale (0-10)	Scale (1-3)	Normalized Scale (0-10)	Scale (1-5)	Normalized Scale (0-10)				
117-001	20 Meadowbrook Rd	Meadow Brook Campus	0.0	0.0	3.0	6.7	3.0	10.0	5.0	10.0	0.75	1	2	10.0
081-002	1531 Main St	Brewster Ambulance Service	0.0	0.0	4.0	10.0	2.0	5.0	5.0	10.0	1	0.5	3	9.4
089-013	371 Main St	The Apostolic Church USA	0.0	0.0	2.0	3.3	3.0	10.0	5.0	10.0	0.5	1	3	8.8
111-040	320 Main St	Old Colony YMCA	0.0	0.0	4.0	10.0	3.0	10.0	5.0	10.0	0.5	1	2	7.5
080-001	2071 Main St	Bank of America Plaza	0.0	0.0	3.0	6.7	3.0	10.0	5.0	10.0	0.5	1	2	6.7
081-247	1717 Main St	Bay State Medical Associates	0.0	0.0	2.0	3.3	3.0	10.0	5.0	10.0	0.5	1	2	5.8
053-010	155 W Elm St	Brockton Cape Verdean Church	0.0	0.0	2.0	3.3	3.0	10.0	5.0	10.0	0.5	1	2	5.8
053-007	137 Newbury St	Old Colony YMCA - David Jon Louison Center	0.0	0.0	4.0	10.0	3.0	10.0	5.0	10.0	0.75	0.5	2	5.6
089-022	Father Kenney Way	Old Colony YMCA - Family Life Center	0.0	0.0	4.0	10.0	3.0	10.0	1.0	0.0	0.5	1	2	5.0
048-379	390 Pleasant St	Sam's Food Stores	0.0	0.0	2.0	3.3	1.0	0.0	5.0	10.0	0.75	1	2	5.0
044-016	409 Pleasant St	Prestige Gas Station	0.0	0.0	2.0	3.3	1.0	0.0	5.0	10.0	0.75	1	2	5.0
117-072	7 Evans St	Churchill Supply Co., Inc.	0.0	0.0	4.0	10.0	2.0	5.0	5.0	10.0	0.25	1	3	4.7
032-105	39 Montauk Rd	Brockton Water Department	0.0	0.0	4.0	10.0	2.0	5.0	5.0	10.0	1	0.25	3	4.7
135-041	52 Perkins St	Geo Knight & Co., Inc.	0.0	0.0	4.0	10.0	2.0	5.0	5.0	10.0	0.25	1	3	4.7
058-043	233 Warren Ave	Boys & Girls Clubs of Metro South - Brockton Clubhouse	0.0	0.0	2.0	3.3	2.0	5.0	5.0	10.0	0.5	1	2	4.6
117-037	1442 Main St	Brockton Area Transit (BAT) Administrative Office	0.0	0.0	4.0	10.0	3.0	10.0	5.0	10.0	0.75	0.25	3	4.2
110-003	65 Crescent St	Verizon Building	0.0	0.0	4.0	10.0	3.0	10.0	5.0	10.0	0.25	1	2	3.8
150-038	142 Crescent St	Gandara Center	0.0	0.0	4.0	10.0	3.0	10.0	5.0	10.0	0.5	1	1	3.8
111-039	304 Main St	Brockton Public Library	0.0	0.0	4.0	10.0	3.0	10.0	5.0	10.0	0.5	1	1	3.8
118-170	1690 Main St	New Heights Charter School	0.0	0.0	4.0	10.0	3.0	10.0	5.0	10.0	0.5	0.5	2	3.8
080-004	1983 Main St	K-mart Plaza	0.0	0.0	4.0	10.0	1.0	0.0	5.0	10.0	0.25	1	3	3.8
125-009	100 Perkins Ave	Walkover Commons Housing	5.0	10.0	1.0	0.0	1.0	0.0	5.0	10.0	0.25	1	3	3.8
048-044	14 Poplar Rd	Residential	4.0	8.0	1.0	0.0	1.0	0.0	5.0	10.0	0.25	1	3	3.4
031-271	450 Pleasant St	Commercial Plaza	0.0	0.0	3.0	6.7	3.0	10.0	5.0	10.0	0.25	1	2	3.3
137-039	Crescent St	Brockton Fire Dept Station #4	0.0	0.0	4.0	10.0	2.0	5.0	5.0	10.0	1.0	0.25	2	3.1

6.3.2 Risk Score Results – Roads & Bridges

Normalized risk scores range from 0 to 10 for both road segments and bridges. Tallied and mapped risk scores for all road segments are available in **Appendix B**. Scoring data for all bridges within the study area and for the highest risk road segments are listed below in **Table 6-4** and **Table 6-5.**

Table 6-4. Risk scores for all bridges within the study area in Brockton, MA

Street Name	Waterbody	Ownership	Flooding Probability	Traffic Count (AADT)		Geographic Extent of Impacts		Normalized Risk Score
				Scale (1-4)	Normalized Scale (0-10)	Scale (1-2)	Normalized Scale (0-10)	
Main St	Salisbury Brook	Municipal	2	4	10.0	2	10	10.0
Perkins Ave	Salisbury Plain River	Municipal	2	2	3.3	2	10	6.7
Carleton St	Salisbury Brook	Municipal	2	1	0.0	2	10	5.0
Forest St	Salisbury Plain River	Municipal	2	1	0.0	2	10	5.0
North Arlington St/ Newbury St	Salisbury Brook	Municipal	2	1	0.0	2	10	5.0
Pine Ave	Salisbury Plain River	Municipal	2	1	0.0	2	10	5.0
Pleasant St	Salisbury Brook	Municipal	2	4	10.0	1	0	5.0
Grove St	Salisbury Brook	Municipal	2	3	6.7	1	0	3.3
Montello St	Salisbury Brook	MassDOT	2	3	6.7	1	0	3.3
Warren Ave	Salisbury Brook	Municipal	2	3	6.7	1	0	3.3
Ash St	Salisbury Brook	Municipal	3	2	3.3	1	0	2.8
Prospect St	Salisbury Brook	Municipal	2	2	3.3	1	0	1.7
Moraine St	Salisbury Brook	Municipal	3	1	0.0	1	0	0.3
Allen St	Salisbury Brook	Municipal	2	1	0.0	1	0	0.0
Otis St	Salisbury Brook	Municipal	2	1	0.0	1	0	0.0
Perkins St	Salisbury Brook	Municipal	2	1	0.0	1	0	0.0
Spring St	Salisbury Brook	Municipal	2	1	0.0	1	0	0.0
White Ave	Salisbury Brook	Municipal	2	1	0.0	1	0	0.0

Table 6-5. Road segments with the 25 highest risk scores in Brockton, MA

Note: Under MassDOT categorization, road segments may have the same name and to/from streets, but can be uniquely identified by "Road Segment ID" and "Route Segment ID."

Route Segment ID (MassDOT)	Road Segment ID (MassDOT)	Street Name	Route Number	Road Class	From Street Name	To Street Name	Flooding Probability	Traffic Count (AADT)		Geographic Extent of Impacts		Normalized Risk Score (0-10)
								Scale (1-5)	Normalized Scale (0-10)	Scale (1-4)	Normalized Scale (0-10)	
N4636 NB	74894	Main St		Major road – arterials/collectors	West Bridgewater Town Line	Court St	2	4	7.5	3	6.7	10.0
SR27 NB	78772	Pleasant St	27	Other numbered route	Rockland St	Main St	2	5	10	2	3.3	9.4
SR27 NB	78774	Pleasant St	27	Other numbered route	Rockland St	Main St	2	5	10	2	3.3	9.4
N4684 EB	77410	West Elm St		Minor street or road	West St	Main St	2	2	2.5	4	10.0	8.8
N4638 NB	77028	Warren Ave		Major road - arterials/collectors	Clifton Ave	Pleasant St	2	3	5	3	6.7	8.2
N4621 NB	75475	Brookside Ave		Major road - arterials/collectors	Main St	Copeland St	2	3	5	3	6.7	8.2
N4706 NB	76773	Summer St		Minor street or road	Plain St	Crescent St	2	4	7.5	2	3.3	7.6
N4635 NB	75658	Grove St		Major road - arterials/collectors	Summer St	Main St	2	4	7.5	2	3.3	7.6
L196772 NB	N/A	Forest St		Minor street or road	Perkins Ave	Auburn St	2	1	0	4	10.0	7.1
L113811 EB	N/A	Ellsworth St		Minor street or road	Newbury St	Dead End	3	1	0	3	6.7	7.1
L180113 NB	N/A	Snow St		Minor street or road	Grove St	Pine Ave	3	1	0	3	6.7	7.1
L160249 NB	N/A	Meadowbrook Rd		Minor street or road	Plain St	Sargents Way	2	1	0	4	10.0	7.1
L109449 NB	N/A	Malvern Rd		Minor street or road	Sycamore St	Lenox St	2	1	0	4	10.0	7.1
L176541 EB	N/A	West Park St		Minor street or road	Warren Ave	Fuller St	2	1	0	4	10.0	7.1
L175920 EB	N/A	Riverview St		Minor street or road	Summer St	Perkins Ave	2	1	0	4	10.0	7.1
L113811 EB	N/A	Ellsworth St		Minor street or road	Newbury St	Dead End	2	1	0	4	10.0	7.1
L232340 EB	N/A	Longworth Ave		Minor street or road	Main St	Thayer Ave	2	1	0	4	10.0	7.1
L232766 EB	N/A	Skyview Dr		Minor street or road	Copeland St	North Main St	2	1	0	4	10.0	7.1
N4705 EB	75338	Perkins Ave		Minor street or road	Summer St	Main St	2	2	2.5	3	6.7	6.5
N4621 NB	75486	Brookside Ave		Major road - arterials/collectors	Main St	Copeland St	2	2	2.5	3	6.7	6.5
N4689 NB	76790	Belmont Ave		Minor street or road	Belmont St	Pleasant St	2	2	2.5	3	6.7	6.5
N4689 NB	74719	Belmont Ave		Minor street or road	Belmont St	Pleasant St	2	2	2.5	3	6.7	6.5
N4681 EB	74518	Prospect St		Minor street or road	North Main St	Pleasant St	2	2	2.5	3	6.7	6.5
N4705 EB	75755	Perkins Ave		Minor street or road	Summer St	Main St	2	2	2.5	3	6.7	6.5
N4689 NB	74656	Belmont Ave		Minor street or road	Belmont St	Pleasant St	3	2	2.5	2	3.3	6.2

6.4 Prioritization Conclusions

By design, the prioritization method employed for this analysis emphasizes economic impacts. While loss of/damage to housing capacity has physical and economic impacts, these losses are relatively straightforward to mitigate through repair or relocation, and the scale of impact is typically limited to the affected families and individuals On the other hand, flooding damage or losses that result in impacts to businesses and employment tend to have more far-reaching effects. Individuals who are out of work lose wages, which has a trickle down impact on their ability to purchase housing and goods from other businesses in the community. Shuttered businesses result in lost tax revenue for the City, as well as lost services for the community, and lost wages for their resident or non-resident employees. Moreover, businesses that lose too much revenue when forced to temporarily close because of flooding may never be able to reopen. Decreases in business and employment capacity contribute to a feedback loop of further decline for the City.

These complex relationships are reflected in the scoring system for parcels, which counts both employer size and employee skill level as independent metrics. The properties with the highest risk scores are thus primarily businesses and institutions serving the larger community by simultaneously providing employment and goods or services. Facilities providing critical services, such as the City water department, and ambulance service also score among the highest risk parcels.

High priority roads and bridges generally reflect those that have the highest usage for travel, in combination with the highest probability of flooding.

Prioritization data will next be used to determine initial areas of focus for nature-based solutions and other flood prevention and resiliency projects. Within and around risk hotspots, individual low-priority sites (e.g. vacant parcels and "underutilized" parcels) may provide viable locations to implement land-intensive nature-based solutions such as floodplain restoration. High-priority sites or residential risk clusters which cannot be adequately protected through implementation of nature-based solutions such as floodplain reconnection or increasing flood storage capacity will be considered for traditional flood protection methods such as raising buildings or constructing flood walls. Relocation of existing parcel uses to less risk-prone locations may also be considered, especially in situations where in situ flood protection or resiliency measures are shown to be either infeasible or not cost-effective.

7 Reducing Runoff at Westgate Mall

7 Reducing Runoff at Westgate Mall

The Westgate Mall and its adjacent commercial properties, referred to herein as the Westgate Mall complex, consists of approximately 133 acres of land. The Westgate Mall complex is located in the City of Brockton directly west of Ellis Brett Pond (EBP) and just northeast of the Route 24 and Route 27 interchange. For purposes of this memorandum, the Westgate Mall complex consists of all development located within and directly abutting the Westgate Drive roadway loop (including, but not limited to, the Westgate Mall, Westgate Lanes, Dick's Sporting Goods, Salvation Army, Lowe's, Harbor Freight Tools, Town Fair Tire, Aspen Dental, etc.). Approximately 85.5% of the complex is covered by impervious surface. Although some of the stormwater runoff generated by the mall complex drains to Thirty Acre Pond during precipitation events, the majority of runoff generated within the complex drains to Lovett Brook. Lovett Brook flows through the southerly section of the mall complex and conveys flow directly to Ellis Brett Pond. Once flow is discharged to Ellis Brett Pond, it is then conveyed through Cross Pond and ultimately to the Salisbury Brook and Salisbury Plain River system.

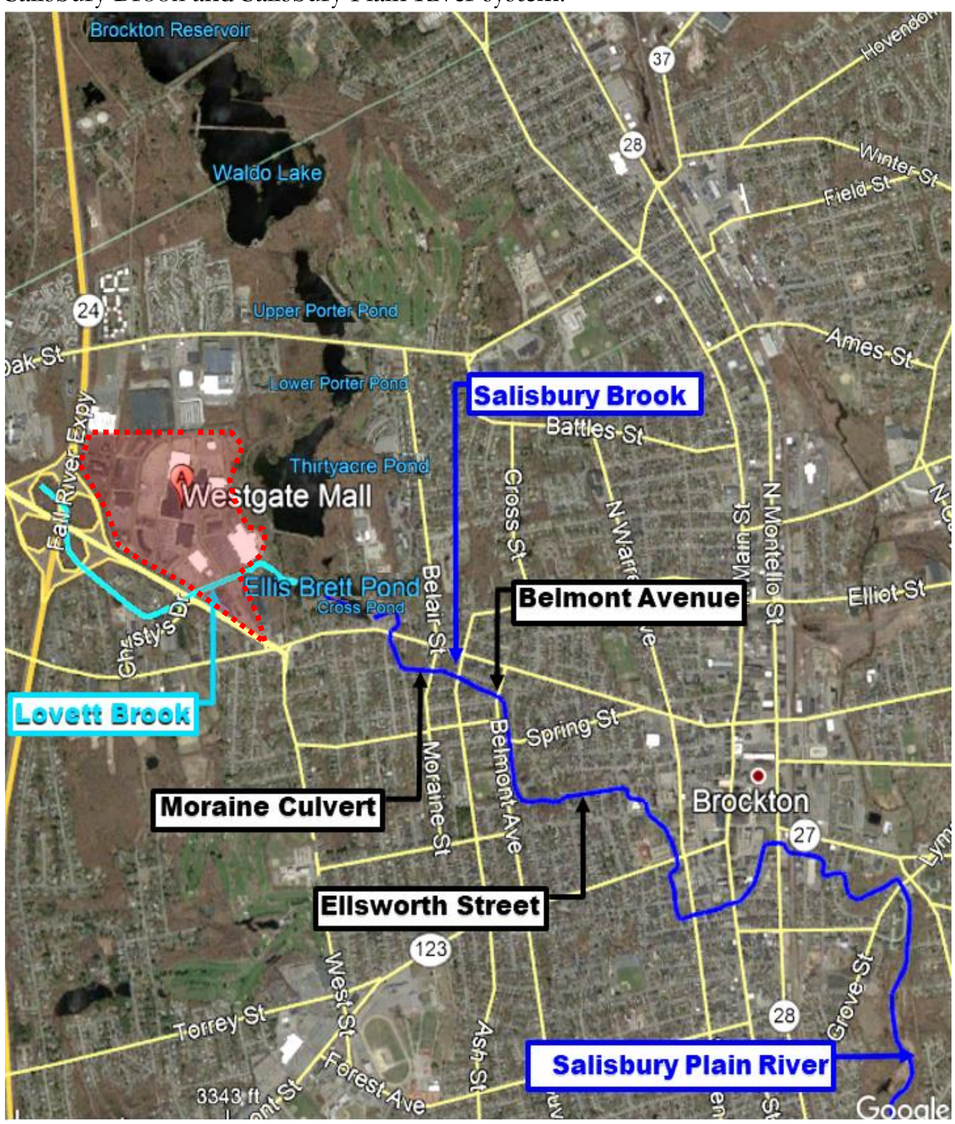


Figure 7-1. Aerial view of Salisbury Brook in Brockton, MA.

While it is evident that runoff generated by the Westgate Mall has contributed to the degradation of water quality within Ellis Brett Pond and flash flooding within Lovett Brook, it has been surmised that runoff generated by the Westgate Mall complex may also be a significant source of flooding along Salisbury Brook and Salisbury Plain River downstream of Ellis Brett Pond. Consequently, the purpose of this memorandum is to summarize the results of Fuss & O'Neill's hydrologic and hydraulic analyses to assess the impacts that installing green infrastructure (GI) measures within the Westgate Mall complex would actually have on reducing peak runoff rates and volumes discharged to Ellis Brett Pond, Cross Pond, and the downstream Salisbury Brook and Salisbury Plain River system; as well as to approximate/ quantify the flooding benefits associated with installing such measures.

The proximity of the mall to the watercourse, along with specific locations of analysis that are referenced in this report such as the Moraine Conduit, Belmont Avenue, and Ellsworth Street, are shown in **Figure 7-1**.

As previously mentioned, the majority of the Westgate Mall complex (approximately 115.2 acres) is located within the Ellis Brett Pond (EBP) Subwatershed. The Westgate Mall complex constitutes approximately 10.8% of the overall Ellis Brett Pond (EBP) Subwatershed. Approximately 85.5% of the complex is covered by impervious surfaces.

In order to better assess the impacts that installing green infrastructure improvements within the Westgate Mall complex would have on reducing peak run off rates and volumes discharged to Ellis Brett Pond, Cross Pond, and the downstream Salisbury Brook and Salisbury Plain River system; the EBP Subwatershed was subdivided into two subwatersheds: one representing the Westgate Mall complex and the second representing the remainder of the EBP Subwatershed. Because the Westgate Mall complex is situated at the downstream end of the overall EBP Subwatershed and has a significant percentage of impervious area, runoff generated by the Westgate Mall area reaches the Lovett Brook and downstream river system sooner than the peak runoff generated by the overall subwatershed as shown in **Figure 7-2**. Rainfall runoff/flood flow hydrographs for each of the EBP Subwatersheds (accounting for the various alternative scenarios considered for the Westgate Mall complex) and the other 18 subwatersheds included within the overall hydrologic model of the Salisbury Brook and Salisbury Plain River[8] were generated using the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) program (Version 4.2.1). These hydrographs were then applied to our hydraulic (HEC-RAS) model of the Salisbury Brook and Salisbury Plain River to quantify the flooding benefits associated with installing such measures.

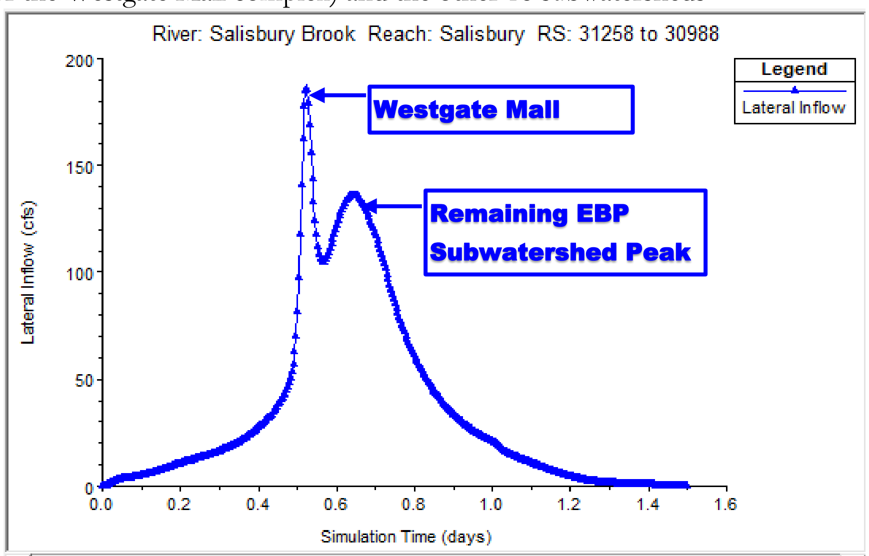


Figure 7-2. Peak runoff timing Comparison between Westgate Mall complex and remaining portion of EBP Subwatershed.

7.1 Summary of Alternatives

Due to the high concentration of impervious area associated with the Westgate Mall complex and its location in close proximity to Ellis Brett Pond and Salisbury Brook, it is postulated by residents and

[8] Hydrologic/Hydraulic Analysis of Salisbury Brook and Salisbury Plain River Integrated Water Infrastructure Vulnerability Assessment and Economic Development, Fuss & O'Neill, Inc. (January 2020)

some City staff that stormwater improvements (including green infrastructure measures) implemented within this mall complex could have a significant impact on reducing downstream peak flows and water surface elevations during flood events.

For purposes of analysis, three practical green infrastructure alternatives (Alternatives 1 through 3) were initially assessed. These alternatives included the installation of bioretention basins, subsurface infiltration systems, or a combination of both types of green infrastructure measures within the mall complex. (Collectively, these alternatives are referred to as stormwater best management practices, or BMPs.) General and detailed locations of each of the green infrastructure measures proposed for each alternative, in addition to the storage volumes provided by each proposed measure, are depicted in **Appendix C**.

Subsequently, five hypothetical alternatives/scenarios were also assessed that included the disconnection of varying levels of impervious surface (or conversion of such impervious surfaces to pervious surfaces). These alternatives/scenarios were assessed in order to gain perspective pertaining to the maximum benefits that could be realized if more extensive measures (as compared to Alternatives 1 through 3) were taken within the Westgate Mall complex to maximize downstream flood benefits.

7.1.1 Alternative 1 – Bioretention (with Minimal Impacts)

Figure 7-3. Conversion of Grassed Islands to Bioretention at Selected Locations.

Many of the parking lots in the mall are bordered by relatively large, grassy islands/strips that would be ideal for implementing green infrastructure improvements or best management practices (BMPs). Converting some of these islands/strips to bioretention basins or bioswales would be a potential way to reduce runoff generated by the mall complex during precipitation events. Since these areas are not paved and are not used for parking, the conversion of these areas from grassed islands/strips to stormwater facilities would require minimal disruption to the layout and day-to-day operations of the complex. Therefore, Alternative 1 consists of the installation of (surface) bioretention basins and bioswales within existing green space areas in the mall area. Of the alternatives proposed within this memorandum, Alternative 1 requires the least disruption to the complex. Existing topography and drainage patterns within the mall complex were reviewed to identify the ideal locations to install these measures.

The approximate locations, footprints, and volumes of storage provided by each of the Alternative 1 BMPs are depicted in green in **Appendix C**. There are seven BMPs included in this alternative that range from 1,100 square feet to 7,400 square feet in footprint/surface area. Volumes for each surface BMP were estimated assuming 1-foot ponding depths and 3(H):1(V) side slopes. BMP lengths and widths were approximated based on open space available, as determined by a combination of aerial imagery and Google Street View.

Due to the limited amount of existing available green space areas in respect to the size of their associated contributing impervious drainage area, the majority of proposed BMPs (assuming a 1-foot depth) were not large enough to fully capture and store 2-year runoff volumes generated by their catchment areas. The total storage capacity provided by the proposed Alternative 1 BMPs is approximately 0.3 acre-feet. To put that into perspective, the volume of runoff generated by their contributing drainage areas is approximately 2.4 acre-feet during the 2-year storm event. Thus, the amount of storage provided by the Alternative 1 BMPs is only approximately 12.5% of the runoff generated by its contributing drainage areas during the 2-year storm event.

7.1.2 Alternative 2 – Bioretention (with Moderate Impacts)

Alternative 2 consists of the seven Alternative 1 BMPs in addition to four more bioretention areas in locations that will require more difficult construction due to the presence of steeper slopes and/or vegetation and the need to convert existing parking spaces/pavement to bioretention. This would potentially require a more thorough review of the zoning ordinance (to make sure that the existing parking lot still meets minimum parking space requirements) and coordination with/concurrence from the property owner that the removal of such parking spaces will not adversely impact business operations. A depiction of each of these added bioretention areas are reflected in **Appendix C**.

- BASIN-04 includes the expansion of BASIN-03 (per Alternative 1) and the conversion of the westernmost row of parking to bioretention area. This will result in the loss of approximately 66 parking spaces but will not impact traffic flow through the lot.
- BASIN-07 proposes the conversion of the southernmost row of parking associated with the Sears building to bioretention area. This will result in the loss of approximately 43 parking spaces but will not impact traffic flow through the lot.
- BASIN-09 proposes the construction of a bioretention area within a sloped intersection corner just east of the Pearle Vision building. This area also contains multiple small trees that would need to be relocated.
- BASIN-11 is proposed within the sloped grass median strip between Westgate Drive and the western perimeter of the Best Buy parking lot. This basin would capture runoff discharged into the parking lot from the roadway via an existing bituminous swale. Due to the cross slope of the median, the construction of this area would require extensive re-grading.

The total storage capacity provided by the proposed Alternative 2 BMPs is approximately 1.1 acre-feet. To put that value into perspective, the volume of runoff generated by the Alternative 2 contributing drainage areas is approximately 4.0 acre-feet during the 2-year storm event. Thus, the amount of storage provided by the Alternative 2 BMPs is approximately 27.5% of the runoff generated by its contributing drainage areas during the 2-year storm event.

7.1.3 Alternative 3 – Combined Bioretention & Subsurface Infiltration

Alternative 3 consists of installing Alternative 1 and 2 BMPs in addition to four subsurface infiltration systems. These systems were strategically proposed in topographical low areas (low points) that were noted during our review of topography within the Westgate Mall complex. Since the amount of available green space within the complex is limited, subsurface infiltration would be a relatively practical option to have more significant reductions on stormwater discharged to Lovett Brook, Ellis Brett Pond, and Salisbury Brook (without causing significant disruptions to parking and traffic flow throughout the complex. The footprints of each proposed subsurface infiltration system are illustrated at the end of **Appendix C** (SUB-12 through SUB-15).

The total storage capacity of these four subsurface infiltration systems is approximately 2.4 acre-feet, which brings the cumulative storage capacity of the Alternative 3 BMPs to approximately 3.5 acre-feet (after including the storage provided by the Alternative 1 and Alternative 2 BMPs). To put that value into perspective, the total volume of runoff generated by the Alternative 3 contributing drainage areas is approximately 7.9 acre-feet during the 2-year storm event. Thus, the amount of storage provided by the Alternative 3 BMPs is approximately 44.3% of the runoff generated by its contributing drainage areas during the 2-year storm.

Figure 7-4. Installation of Subsurface Infiltration at Selected Locations.

7.1.4 BMP Size & Cost Comparison for Alternatives 1 through 3

A breakdown of the three alternatives by capacity, surface area, and order of magnitude cost is shown in **Table 7-1**.

Order of magnitude costs are approximate only based on the assumed sizes of proposed BMPs and include a 30% contingency, engineering design and permitting, and construction administration.

Table 7-1. Runoff Volume Reductions for Green Infrastructure BMP Alternatives 1 through 3

	Number of BMPs	Footprint Area of BMP (ft^2)	Total Storage Volume (ft^3)	Total Storage Volume (ac-ft)	Opinion of Cost**
Alternative 1	7	16,640	14,920	0.3	$544,800
Alternative 2*	11	53,520	46,810	1.1	$1,522,600
Alternative 3	15	73,180	152,500	3.5	$3,098,800

* Alternative 2 includes expansion of BMP (BASIN-03) from Alternative 1.
** These costs are for high-level planning purposes only and do not include annual operation, maintenance, and inspection.

7.2 Hydrologic & Hydraulic Analysis Summary

Each alternative was evaluated in our HEC-HMS (hydrologic) model by retaining an equivalent volume of runoff generated by the EBP Westgate Mall Subwatershed. To achieve this, the area of EBP Westgate Mall Subwatershed (0.18 square miles) was reduced to an area that produced the desired volume of runoff reduction for each storm event. Only the 2- and 10-year events were analyzed for this analysis, as stormwater retention measures will have less impact, proportionally, on flooding for the larger events.

7.2.1 Analysis Results for Alternatives 1 through 3

Table 7-2 lists the reduced subwatershed area values applied to the EBP Westgate Mall Subwatershed in order to achieve the equivalent runoff volume reduction associated with the implementation of BMPs associated with Alternatives 1 through 3.

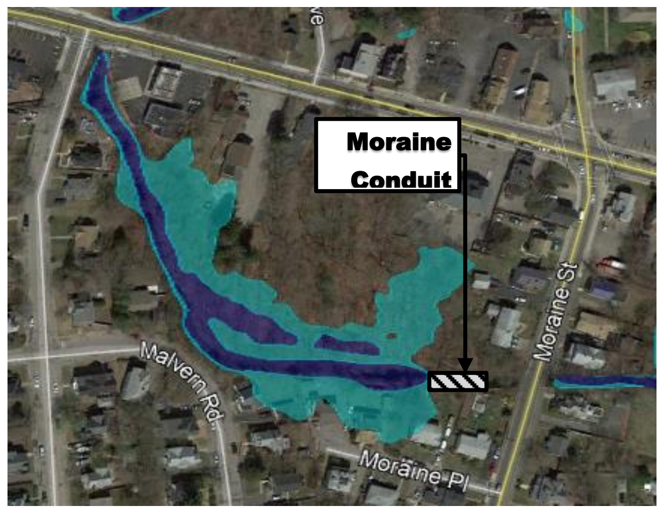
Under existing conditions, the total volume of runoff generated by the EBP Westgate Mall Subwatershed over the duration of the 2- and 10-year storms is 27.5 and 41.6 acre-feet, respectively. Therefore, retention volumes that could be achieved by implementing BMPs associated with these three alternatives are 1.1% to 12.7% of the Westgate Mall Subwatershed runoff volume produced during the 2-year storm, and 0.7% to 8.4% of the 10-year runoff volume. However, it must be understood that the Westgate Mall complex constitutes only 10.8% of the overall EBP Subwatershed. When comparing these runoff volume reductions to the overall EBP Subwatershed runoff volumes, these volume reductions only constitute 0.3% to 3.3% of the overall watershed runoff volume produced during the 2-year storm, and 0.2% to 2.0% of the overall 10-year runoff volume.

Table 7-2. Runoff Volume Reduction and Equivalent Subwatershed Area Associated with Proposed Alternative 1-3 Improvements

Alternative	Runoff Reduction (ac-ft)	2-Year Equiv. Subwatershed Area (sq. mi.)	10-Year Equiv. Subwatershed Area (sq. mi.)
Existing Conditions	0.0	0.1800	0.1800
Alternative 1	0.3	0.1780	0.1786
Alternative 2	1.1	0.1730	0.1755
Alternative 3	3.5	0.1570	0.1651

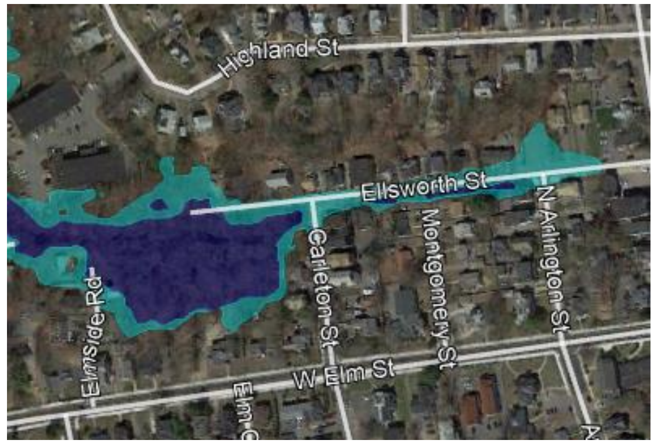
In order to quantify decreases in water surface elevations that would be anticipated in Salisbury Brook as a result of runoff volume reductions associated with the implementation of Alternatives 1 through 3, the equivalent subwatershed areas for the EBP Westgate Mall Subwatershed listed in **Table 7-2** (for each alternative) were applied to our hydrologic (HEC-HMS) model. Updated flow hydrographs for each alternative during the 2- and 10-year storm events were then applied to our hydraulic (HEC-RAS) model of the Salisbury Brook and Salisbury Plain River. After reviewing the results of the analyses, it was concluded that perceptible decreases in maximum water surface elevations (WSEs) due to the influence of Alternatives 1 through 3 were generally limited to the Salisbury Brook and were not observed as far downstream as the Salisbury Plain River. This is likely due to the introduction of the larger contributing flow (i.e. from Trout Brook) entering the downstream river system that limits the relative impact of the flow reductions from Lovett Brook. Impacts of the Westgate Mall runoff reduction alternatives were evaluated at the following areas along the Brook that were identified as flood problem areas during the 2-year and 10-year storm events:

1. **Moraine Conduit** – Upstream of Moraine Street is a large concrete box culvert that restricts flow. Only extremely low flows (less that of the 2-year flood event) can pass through this culvert without being restricted. During larger flows, the structure functions as a restriction that impounds flows resulting in overbank flooding. For purposes of this analysis, flood impacts are quantified upstream of this conduit near the outfall/culvert entering the Brook at Malvern Road.



2. **Belmont Avenue** – The neighborhood surrounding Belmont Avenue is known to be highly susceptible to flooding during significant storm events (including the 2-year and 10-year storms). In the early 2000's, four properties downstream of Belmont Avenue were purchased for buy-out and demolished due to repetitive flooding. For purposes of this analysis, flood impacts are quantified downstream of the Belmont Avenue bridge as they were typically greater than computed on the upstream side.

3. **Ellsworth Street** – Within the Ellsworth Street Area, the Brook is buried and consists of several long conduits that run parallel to Ellsworth Street (between Carleton and Newbury Streets) before being conveyed underground for approximately 970 feet beneath West Elm Street and Eldon B. Keith Memorial Field. For purposes of this analysis, impacts are quantified upstream of the Newbury Street bridge.



4. **Cold Spring Brook Area** – In this location, the rear yards of residential properties that border Cold Spring Brook on the northwestern side of the Fuller Street/Winthrop Street intersection experience flooding likely due to backwater impacts associated with elevated flood levels in Salisbury Brook. Inundation of actual structures, however, does not occur until the 10-year flood. Although no process-based flood modeling was performed individually for Cold Spring Brook and the extent of flooding along Cold Spring Brook does not take into account any culvert restrictions associated with piped storm drain systems discharging to the Cold Spring Brook, it is likely that reducing water levels in Salisbury Brook (near Tartaglia Park) will help minimize flooding in this area.

5. **Perkins/Otis Street** – Portions of mixed-use properties along Salisbury Brook between Perkins Street and Otis Street experience varying levels of inundation during the 2-year and 10-year floods. This area is located approximately 1,400 feet upstream of the Salisbury Brook's confluence with Trout Brook.

Maximum water surface elevation (WSE) profiles for each alternative are compared with the base conditions model for the 2- and 10-year events at the previously mentioned locations. These profiles are included in **Appendix C**. **Table 7-3** below lists the reduction in 2-year WSEs for each alternative at each point of analysis; **Table 7-4** lists the reduction in WSEs for the 10-year event.

Table 7-3. Water Surface Elevation Reductions for 2-Year Event

		2-Year Max. WSE Reduction (in.)				
Alternative	Runoff Reduction (ac-ft)	Moraine Conduit	Belmont Avenue	Ellsworth Street	Cold Spring Area	Perkins/Otis Street
Alternative 1*	0.3	0.2	0.1	0.0	0.1	0.0
Alternative 2*	1.1	0.5	0.3	0.2	0.2	0.1
Alternative 3*	3.5	1.8	0.9	0.6	0.8	0.5

* Alternatives are depicted in **Appendix C**

Table 7-4. Water Surface Elevation Reductions for 10-Year Event

		10-Year Max. WSE Reduction (in.)				
Alternative	Runoff Reduction (ac-ft)	Moraine Conduit	Belmont Avenue	Ellsworth Street	Cold Spring Area	Perkins/Otis Street
Alternative 1*	0.3	0.1	0.1	0.0	0.0	0.0
Alternative 2*	1.1	0.5	0.2	0.2	0.0	0.0
Alternative 3*	3.5	1.6	0.7	0.5	0.1	0.1

* Alternatives are depicted in **Appendix C**

As shown in the above tables, the green infrastructure improvements proposed for Alternatives 1 through 3 produce only minimal water surface elevation reductions through the Salisbury Brook and Salisbury Plain River system. Even the most intensive of the three alternatives, Alternative, 3 which includes the implementation of four subsurface infiltration systems in Westgate Mall and requires the loss of approximately 20,000 square feet of parking lot space, does not result in appreciable reductions in downstream WSEs.

- For the 2-year event, the greatest reduction in WSEs is estimated to be approximately 1.8 inches in the area upstream of the Moraine conduit as a result of the installation of Alternative 3 BMPs. For Alternatives 1 and 2, none of the locations analyzed will experience a WSE reduction greater than 0.5 inches.
- For the 10-year event, the greatest reduction in WSEs is estimated to be approximately 1.6 inches in the area upstream of the Moraine conduit as a result of the installation of Alternative 3 BMPs. For Alternatives 1 and 2, none of the locations analyzed will experience a WSE reduction greater than 0.5 inches.

Overall, while the proposed alternative BMPs may improve the water quality and flashiness of flows conveyed by Lovett Brook, it appears that they have little impact on flood conditions experienced downstream in Salisbury Brook and Salisbury Plain River. This appears to be largely because the Westgate Mall complex constitutes only approximately 10.9% of the overall Ellis Brett Pond (EBP) Subwatershed. Providing BMPs that only accommodate 0.3 to 3.5 acre-feet of storage, which in turn represents only 0.3% to 3.3% of the overall watershed runoff volume produced during the 2-year storm and 0.2% to 2.0% of the 10-year runoff volume, is simply not adequate to have appreciable flooding impacts downstream.

7.2.2 Hypothetical Alternatives & Analysis Results (Alternatives 4 through 8)

The limited benefits observed from implementing the BMPs associated with Alternatives 1 through 3 indicates that a more aggressive approach to reduce runoff volumes generated by the Westgate Mall complex would be required to have appreciable flood reduction benefits to the downstream river system. As a result, four additional alternatives were considered and analyzed. These alternatives are considered hypothetical scenarios and are defined by varied amounts of runoff reductions. For example, Alternatives 4, 5, 6, and 7 represent green infrastructure BMPs/measures that would result in 5, 10, 15, and 20 acre-foot runoff volume reductions, respectively. An extreme hypothetical scenario, Alternative 8, was also developed to gain a better theoretical understanding of the impact of the mall and the maximum flood reduction benefits that could be expected should extreme green infrastructure measures be installed within the mall complex. Under this alternative, it was assumed that all impervious surface cover within the mall complex would be converted to pervious cover.

To simulate runoff volume reductions for the EBP Westgate Mall Subwatershed within the hydrologic model for Alternatives 4 through 7, the existing subwatershed area calculated for the EBP Westgate Mall Subwatershed (0.18 square miles) was reduced to a value that produced the desired reduction in runoff volume for each hypothetical alternative (for each storm event). To simulate runoff volume reductions for the EBP Westgate Mall Subwatershed within the hydrologic model for Alternative 8, the existing impervious percentage for the EBP Westgate Mall Subwatershed (85.5%) was reduced to zero percent to reflect the conversion of all impervious surfaces within the complex to pervious surfaces. **Table 7-5** lists the reduced subwatershed areas (for Alternatives 4-7) or the reduced impervious percentage value (for Alternative 8) that were applied to the EBP Westgate Mall Subwatershed in order to achieve the equivalent runoff volume reduction associated with each of the hypothetical alternatives.

Table 7-5. Runoff Volume Reduction and Equivalent Subwatershed Area or Impervious Area Percentage Associated with Hypothetical Alternatives 4-8

Alternative	Runoff Reduction (ac-ft)	Equivalent Impervious Area %	2-Year Equiv. Subwatershed Area (sq. mi.)	10-Year Equiv. Subwatershed Area (sq. mi.)
Existing Conditions	0.0	85.45%	0.1800	0.1800
Alternative 4 – 5 ac-ft Retained	5.0	85.45%	0.1475	0.1586
Alternative 5 – 10 ac-ft Retained	10.0	85.45%	0.1145	0.1369
Alternative 6 – 15 ac-ft Retained	15.0	85.45%	0.0820	0.1153
Alternative 7 – 20 ac-ft Retained	20.0	85.45%	0.0490	0.0937
Alternative 8 – Westgate Converted to Pervious*	27.5 – 39.4	0%	0.1800	0.1800

* The Westgate Mall Subwatershed, as defined in the HEC-HMS model, is covered by approximately 85.45% of impervious cover. For Alternative 8, this percentage was reduced to 0% in order to reflect the conversion of the entire Westgate Mall area to pervious surface.

To quantify decreases in water surface elevations that would be anticipated in Salisbury Brook as a result of runoff volume reductions associated with the implementation of Alternatives 4 through 8, the equivalent subwatershed areas for the EBP Westgate Subwatershed listed in **Table 7-5** (for each

Table 7-6. Water Surface Elevation Reductions for 2-Year Event

		2-Year Max. WSE Reduction (in.)				
Alternative	Runoff Reduction (ac-ft)	Moraine Conduit	Belmont Avenue	Ellsworth Street	Cold Spring Area	Perkins/ Otis Street
Alternative 4 – 5 ac-ft Retained	5	2.6	1.2	0.8	1.1	0.7
Alternative 5 – 10 ac-ft Retained	10	**5.1**	2.5	1.7	2.3	1.6
Alternative 6 – 15 ac-ft Retained	15	**7.8**	**4.1**	**3.0**	2.7	1.9
Alternative 7 – 20 ac-ft Retained	20	**9.6**	**5.3**	**4.4**	**3.1**	2.2
Alternative 8 – Westgate Converted to Pervious	27.5	**11.0**	**7.2**	**6.3**	3.8	2.6

Table 7-7. Water Surface Elevation Reductions for 10-Year Event

		10-Year Max. WSE Reduction (in.)				
Alternative	Runoff Reduction (ac-ft)	Moraine Conduit	Belmont Avenue	Ellsworth Street	Cold Spring Area	Perkins/ Otis Street
Alternative 4 – 5 ac-ft Retained	5	2.3	1.0	0.7	0.2	0.1
Alternative 5 – 10 ac-ft Retained	10	4.5	2.1	1.5	0.3	0.2
Alternative 6 – 15 ac-ft Retained	15	**6.6**	**3.4**	2.7	0.5	0.3
Alternative 7 – 20 ac-ft Retained	20	**7.5**	**4.8**	**3.9**	0.7	0.4
Alternative 8 – Westgate Converted to Pervious	39.4	**10.8**	**10.1**	**8.4**	1.7	1.1

alternative) were applied to our hydrologic (HEC-HMS) model. Updated flow hydrographs for each alternative during the 2- and 10-year storm events were then applied to our hydraulic (HEC-RAS) model of the Salisbury Brook and Salisbury Plain River. Maximum water surface elevation (WSE) profiles for each alternative were compared with the base conditions model for the 2- and 10-year events at the previously mentioned locations. These profiles are included in **Appendix C**. **Table 7-6** lists the reduction in 2-year WSEs for each alternative at each point of analysis; **Table 7-7** lists the reduction in WSEs for the 10-year event.

As expected, greater flood reduction benefits are anticipated for the hypothetical scenarios. **Figures 7-5 and 7-6** below show a comparison of the maximum reductions that are anticipated for the hypothetical scenarios in respect to Alternatives 1 through 3 for the 2- and 10-year events, respectively.

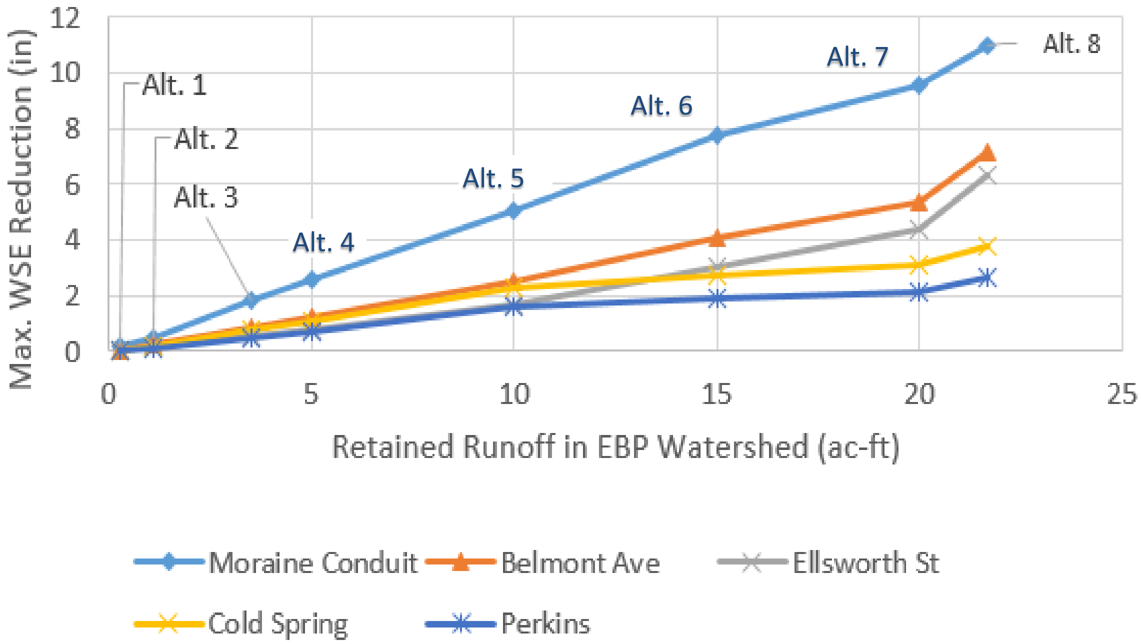


Figure 7-5. Hypothetical reductions in peak WSE for the 2-year event at locations of interest along Salisbury Brook resulting from runoff reduction in the Westgate Mall EBP watershed.

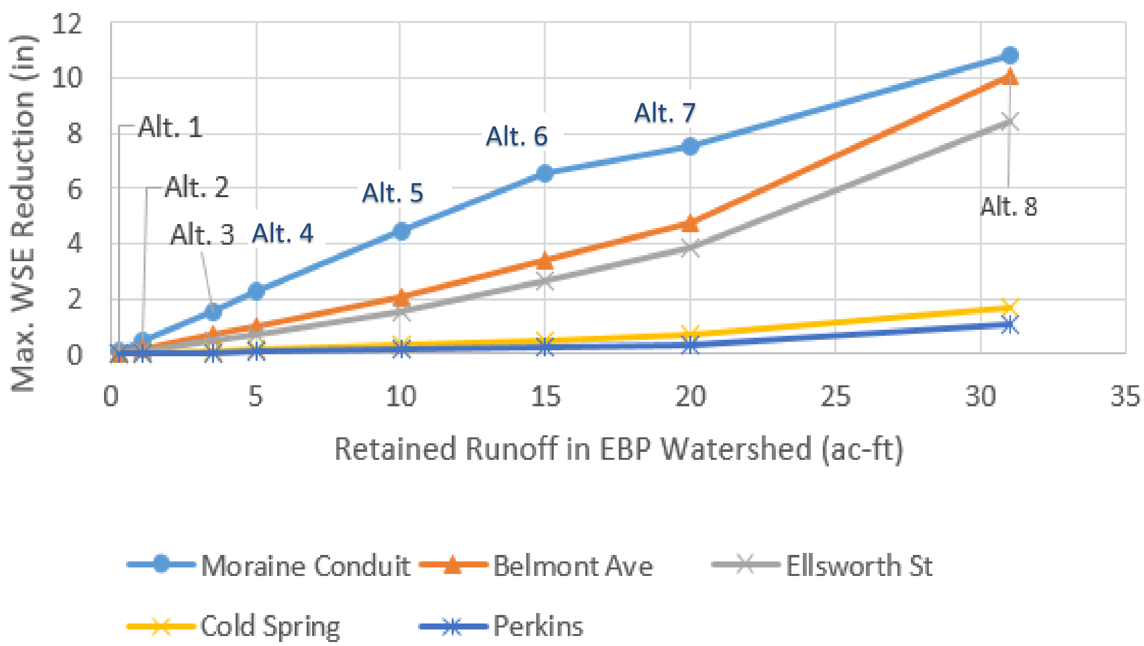


Figure 7-6. Hypothetical reductions in peak WSE for the 10-year event at locations of interest along Salisbury Brook resulting from runoff reduction in the Westgate Mall EBP watershed.

For the 2-year and 10-year events for all hypothetical scenarios, the greatest measureable impact on WSEs occurs upstream of the Moraine conduit. In general, the impacts diminish as flow moves further downstream along Salisbury Brook with WSE reductions becoming negligible after flow from Trout Brook is introduced.

- For the 2-year event, the greatest reduction in WSEs is estimated to be approximately 11.0 inches in the area upstream of the Moraine conduit as a result of full conversion of the Westgate Mall complex to pervious surface. It should also be noted that WSE reductions of between 5.1 inches and 9.6 inches were calculated for Alternatives 5 through 7, respectively, upstream of the Moraine conduit. However, a reduction of only 2.6 inches was calculated for Alternative 4 improvements.
- For the 10-year event, the greatest reduction in WSEs is estimated to be approximately 10.8 inches in the area upstream of the Moraine conduit as a result of full conversion of the Westgate Mall complex to pervious surface. It should also be noted that WSE reductions of between 4.5 inches and 7.5 inches were calculated for Alternatives 5 through 7, respectively, upstream of the Moraine conduit. However, a reduction of only 2.3 inches was calculated for Alternative 4 improvements.

Overall, greater benefits in water surface elevations are expected for the hypothetical scenarios (Alternatives 4 through 8) than the more practical Alternatives 1 through 3. The greatest flood reduction benefits observed extend from the section of the Brook upstream of the Moraine conduit through the Ellsworth Avenue area just before flow enters the underground culvert downstream of Newbury Street. WSE impacts then diminish as a result of the implementation as flow moves further downstream along Salisbury Brook with WSE reductions becoming negligible after the Brook's confluence with Trout Brook. Although flood reductions are more significant for Alternatives 4 through 8 as compared to Alternatives 1 through 3, only during Alternatives 6 and greater are WSE reductions of three inches or greater expected in locations upstream of the Moraine conduit and through the Ellsworth Avenue neighborhood.

Refer to **Appendix C** for water surface profiles associated with each alternative for the 2- and 10-year storm events.

7.3 Conclusion

The most notable takeaway from this analysis is the surprising lack of flood reduction benefits anticipated for the majority of alternatives considered in this analysis including the extreme, hypothetical scenario (Alternative 8) of converting the entire Westgate Mall to pervious surface. This extreme alternative gives context to the minimal flood reduction benefits that would be anticipated for the more practical GI alternatives such as Alternatives 1 through 3. Alternative 3, which was considered the most intensive of the first three alternatives as it proposed both surface and subsurface systems, would only retain 3.5 acre-feet of runoff. This is approximately 9 percent to 13 percent of what would be retained in under the extreme Alternative 8 scenario for the 2-year and 10-year flood events, respectively. Therefore, stormwater improvements proposed within the Westgate Mall complex for Alternatives 1 through 3 will have negligible flood reduction benefits.

In order to have appreciable downstream flood reduction benefits in critical flood locations along Salisbury Brook , stormwater improvements that would provide an approximate flood volume reduction of 15 acre-feet or greater would need to be implemented in the Westgate Mall complex. This would be equivalent to improvements anticipated from Alternatives 6 through 8.

- To have appreciable flood reduction benefits in the Belmont Area, including the elimination of the Sycamore and Belmont Avenue intersection from the 2-year inundation area, stormwater improvements that would provide an approximate flood volume reduction of 20 acre-feet or greater would need to be implemented in the Westgate Mall complex. This would be equivalent to improvements anticipated from Alternatives 7 and 8.

- To have appreciable flood reduction benefits within the Ellsworth Street neighborhood, including the removal of the roadway from the 10-year inundation area, stormwater improvements that would provide an approximate flood volume reduction of 15 acre-feet or greater would need to be implemented in the Westgate Mall complex. This would be equivalent to improvements anticipated from Alternatives 6, 7, and 8.

The model also shows that WSE impacts diminish downstream of the Ellsworth Street neighborhood area and as flow moves further downstream along Salisbury Brook. WSE reductions then become negligible after the Brook's confluence with Trout Brook where a significant amount of flow is introduced into the river system.

In summary, the results of this analysis conclude that stormwater improvements within the Westgate Mall complex will have minimal benefits in terms of flood reduction within Salisbury Brook and Salisbury Plain River unless stormwater improvement measures are applied that will result in a 15 acre-foot reduction or greater in runoff volumes from the complex. And while such improvements will improve flooding conditions (i.e. at the Belmont Avenue and Ellsworth Street neighborhood areas) in the stretch of the Salisbury Brook from Ellis Brett Pond to entrance of the underground culvert just downstream of Newbury Street during the more frequent flooding events including the 2- and 10-year storms, it will not alleviate flooding during such events. There will also be some reductions in flood elevations experienced further downstream up until the Brook's confluence with Trout Brook, but such reductions will be limited to 4 inches or less during the 2- and 10-year storms. Therefore, it is not recommended to invest in the proposed stormwater alternatives solely based on flood reduction benefits unless these measures are combined with other restoration and/or structural improvements along the Brook.

It should be noted, however, that while flood reduction benefits would be minimal for BMPs implemented at Westgate Mall, there would still be a water quality benefit associated with these measures and a potential for improved hydraulics through Lovett Brook during flashy rainfall events. While this task does not include quantification of such benefits, it is worth stating. If it becomes a priority to improve water quality in Ellis Brett and Cross Ponds, the measures analyzed in this report should be considered.

7.4 Limitations of Analysis & Other Considerations

In order to improve the accuracy of this analysis, the drainage area of the Westgate Mall complex could be confirmed and/or refined through mapping and/or field survey(s) of stormwater infrastructure that currently exists throughout the complex. Although Fuss & O'Neill did request this type of information from the City at the start of this task, we were informed that stormwater conveyance infrastructure (e.g., catch basins, piping, subsurface systems) in the Westgate Mall area was not available or could not be found. Although Fuss & O'Neill was able to determine approximate drainage patterns from LiDAR topography and identify several catch basins through street view and aerial imagery review, the exact hydraulic connections between drainage structures or the presence of subsurface stormwater management structures could not fully be determined. Despite this lack of information, BMPs were sited and catchments were approximately delineated using the best information available. Therefore, the accuracy of these elements and results, even at the planning stage, should be evaluated with this in mind.

While this report presents an evaluation of green infrastructure alternatives at Westgate Mall and potential corresponding flood benefits to each, the following additional considerations that are beyond the scope of this task should be further investigated and evaluated as part of Task 6 since the Westgate Mall complex alternatives do not have significant flood reduction benefits alone.

- Analyze the potential flood reduction benefits that could be achieved by increasing flood storage volumes in Ellis Brett Pond and Cross Pond through dredging or excavation.
- Analyze the potential flood reduction benefits that could be achieved by developing a stop-log/gate management strategy at Ellis Brett Pond during the more frequent flood events such as the 2-year and 10-year storm events or smaller. Since the 1970s or 1980s, Ellis Brett Pond has been maintained in relatively dry conditions. Consequently, water that enters the pond is discharged through the spillway with little attenuation. Developing a stop-log/gate management strategy to maximize the storage benefits of Ellis Brett Pond during these events could reduce flooding impacts downstream of Ellis Brett Pond through the controlled release of downstream flows. This strategy, however, would require coordination and a commitment by the City to continuously monitor rainfall events and maintain spillway boards accordingly.
- Analyze the potential flood benefits that could be achieved by installing a low-flow notch in the Cross Pond spillway. Currently, the normal water level in Cross Pond is governed largely by the elevation of its spillway crest. Therefore, the pond provides little attenuation of flow and/or flood strorage during storm events. Installing a low-flow notch could be an option that would allow for the lowering of the normal water level of the pond; thereby increasing the amount of flood storage available during rainfall events. The size and invert of the low-flow notch would need to be designed such that a minimum desired water level would be maintained in the pond for ecological purposes during dry-weather conditions. This alternative could be proposed in conjunction with increasing the flood storage volume of Cross Pond.

8 Nature-Based Solutions

Using Fuss & O'Neill's refined and more up-to-date hydrologic and hydraulic model of the Salisbury Brook (Brook) and Salisbury Plain River (River), several nature-based solutions to reduce flooding throughout the City were assessed using HEC-RAS (Version 5.0.6). This assessment included an evaluation of three variations of each of the following alternatives to quantify potential risk reduction:

- Dredging and Ecological Enhancement of Ellis Brett Pond
- Dredging and Ecological Enhancement of Cross Pond
- Flood Plain Restoration at Undeveloped Parcels along the Brook/River
- Flood Plain Restoration of Developed Sites along the Brook/River

Each of these alternatives focuses on restoring and/or enhancing the natural habitat and flood storage functions of the ponds and/or floodplain areas immediately surrounding the river system in order to increase flood storage and lower water surface elevations experienced throughout the river system during flood events. This, in turn, will reduce flood risk for homes and businesses along the Salisbury Brook and Salisbury Plain River system. The results of our hydraulic analyses for each nature-based alternative are discussed in more detail within this report. Order of magnitude cost/benefit analyses for each alternative are also provided.

8.1 Ellis Brett Pond Excavation, Gate Management, & Ecological Enhancement

Ellis Brett Pond currently has a normal pool surface area of approximately 1.6 acres and normally holds approximately 13,000 cubic yards (or 8.1 acre-feet) of water. The pond is impounded by a dam and is generally maintained under dry conditions with minimal flow controls (weir boards) applied to the dam's primary spillway. The primary spillway is a concrete sluiceway consisting of a two-bay concrete stop log structure. Each bay has a 5.0-foot wide by 5.27-foot high opening (with an invert elevation of El. 139.56 feet). The crest elevation of the dam varies due to minor surface undulations, but has an average elevation of El. 148.0 feet (NAVD88). The maximum storage volume of the pond, below this elevation, is approximately 78,200 cubic yards (or 48.4 acre-feet).

Figure 8-1. Aerial View of Ellis Brett Pond (Present-Day Conditions)

It should be noted that the City is currently in the final design and permitting stages of constructing improvements to the Ellis Brett Pond Dam. Following these improvements, the pond will have a consistent crest elevation of El. 148.3± feet (NAVD88), a reconstructed primary spillway consisting of two 5.0-foot wide by 5.27-foot high openings (with an invert elevation of El. 139.56 feet), and an overflow spillway (with a crest elevation of El. 147.30 feet) that will convey excess flood flow downstream to Cross Pond. For purposes of this analysis, the Ellis Brett Pond Dam reflects the proposed layout and configuration of the dam subsequent to these planned dam improvements.

Given the amount of freeboard that exists within the pond during the 2- and 10-year flood events, the following three alternatives were developed to assess the flood reduction benefits that could be realized downstream if flood storage benefits at Ellis Brett Pond were maximized.

- Ellis Brett Alternative 1 (EB-1) - Perform excavation of a section of the vacant (wooded) area immediately to the north of Ellis Brett Pond above the pond's normal water level to increase the storage volume of the pond by approximately 42,600 cubic yards (or 18.0 acre-feet).
- Ellis Brett Alternative 2 (EB-2) – Install a gate at the pond's primary spillway and develop a gate management strategy to maximize water retention/storage for the analyzed flood events.
- Ellis Brett Alternative 3 (EB-3) – Combine improvements from Ellis Brett Alternatives 1 and 2.

8.1.1 Alternative EB-1 Summary & Hydraulic Analysis Results

This alternative proposes the clearing and excavation of a 9.8-acre area primarily to the north of the normally inundated section of Ellis Brett Pond that exists above the pond's normal water surface elevation. This will result in the removal of approximately 42,600 cubic yards of material between El. 140.0± (NAVD88) and El. 148.0± (NAVD88) which approximately represents the normal water surface elevation of Ellis Brett Pond and the top of the dam, respectively. This alternative also assumes that the dam's existing primary spillway will remain fully open/available to pass flow without any means of flow control as is the case under present-day conditions.

Based on the results of our analysis, it appears that increasing the storage volume of Ellis Brett Pond will have the following impacts to downstream water surface elevations during the analyzed flood events as shown in **Table 8-1**. Values shaded in light blue indicate locations where flood reductions will exceed two inches.

Figure 8-2. Alternative EB-1 Proposed Excavation Limits

Table 8-1. Ellis Brett Alternative EB-1 Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Elmwood Avenue to Prospect Street	-0.2	-0.3	0.0	0.0	0.0
Prospect Street to Pleasant Street	-0.2	-0.3	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	-0.5	-0.5	-0.2	-0.2	-0.1
Moraine Street Conduit to Ash Street	-0.4	-0.4	-0.5	-0.6	-0.1
Ash Street to Belmont Avenue	-0.4	-0.3	-0.2	-0.3	-0.1
Belmont Avenue to Carleton Street	-0.2	-0.2	-0.2	-0.1	-0.1
Carleton Street to No. Arlington Culvert	-0.4	-0.3	-0.2	0.0	-0.1
Belmont Street (123) to Warren Avenue	-0.3	-0.3	-0.1	-0.1	-0.1
Warren Avenue to Allen Street	-0.3	-0.2	-0.1	-0.1	0.0
Allen Street to White Avenue	-0.2	-0.1	-0.5	-0.1	0.0
White Avenue to Railroad Bridge	-0.3	-0.2	-0.6	-0.2	0.0
Railroad Bridge to Otis Street	-0.2	-0.1	-0.4	-0.2	-0.1
Otis Street to Grove Street	-0.1	-0.1	-0.2	-0.1	-0.1
Grove Street to Pine Avenue	-0.1	-0.1	-0.1	0.0	0.0
Pine Avenue to Perkins Avenue	-0.1	-0.1	-0.1	0.0	0.0
Perkins Avenue to Plain Street	-0.1	-0.1	-0.1	-0.1	0.0
Plain Street to Sargent's Way	-0.1	-0.1	0.0	-0.1	0.0
Sargent's Way to WWTF/K-Mart Plaza	-0.1	0.0	0.0	0.0	0.0

Notes:

1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

Based on the results shown in the table above and within **Figure 8-2**, it appears that this alternative will have flood reductions of greater than 2 inches throughout the majority of Salisbury Brook during the 2- through 10-year flood events. The Belmont Avenue Bridge would also no longer overtop during the 2-year flood. Reductions of greater than 2 inches were also noted within a few sections of the Brook during the 50- and 100-year flood events. However, the maximum reductions seen in flood levels with this alternative are limited to six to seven inches during the flood events analyzed.

To limit the growth of vegetation beneath the normal pond elevation throughout the entire proposed limits of excavation, additional excavation could be performed to maintain a constant stand of water throughout the pond below El. 139.56 feet (NAVD88). This volume, however, would not increase the amount of storage available during floods since it is below the pond's normal water surface elevation and will be occupied by water at the onset of the flood events.

The proposed excavation limits modeled in this analysis represent the maximum extent of potential excavation. Portions of this proposed potential excavation area are mapped by MassDEP as various types of wetlands. Permitting constraints may limit the actual usable area available for excavation. In addition, the presence of wetlands suggests a high seasonal groundwater table. Excavating below the level of seasonal high groundwater, even if able to be permitted, may have limited benefits, since the area may fill in with standing water, precluding its availability for flood storage when needed. If this alternative were to be pursued, groundwater monitoring would be recommended before proceeding with design and permitting. Upland areas at the eastern and western extents of the proposed excavation areas should face fewer challenges for conversion to flood storage, but limiting excavation to these areas would yield only partial benefits relative to the results presented here.

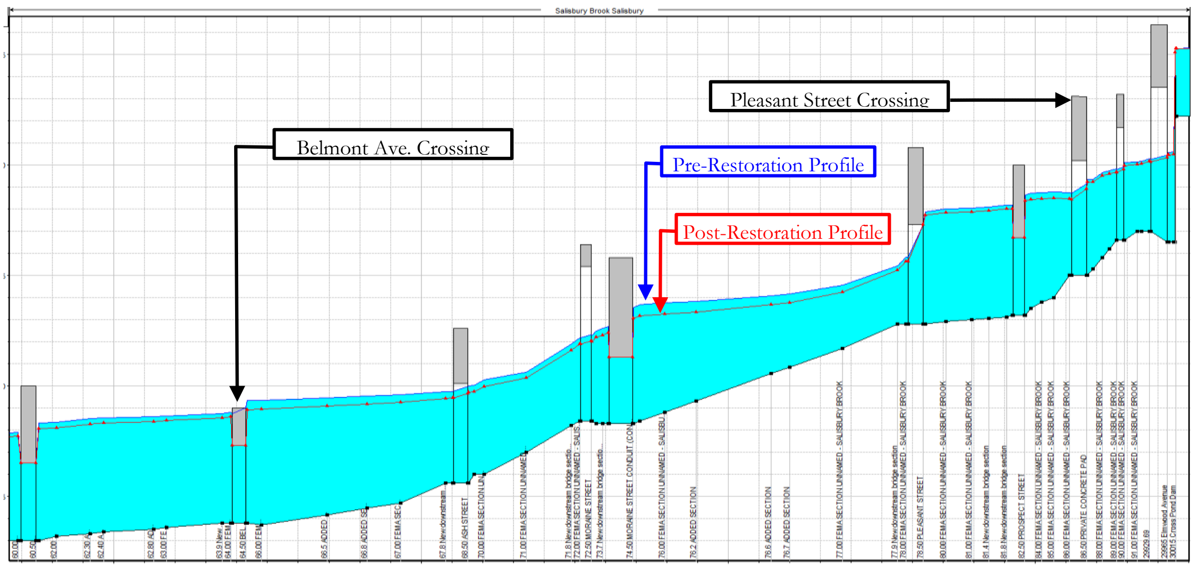


Figure 8-3. Alternative EB-1 Pre- Versus Post-Improvement 2-Year Water Surface Elevation Profile Comparison

8.1.2 Alternative EB-2 Summary & Hydraulic Analysis Results

This alternative proposes the installation of a bottom-hinged (remotely controlled) crest gate within the dam's primary spillway openings. To take advantage of the existing volume of flood storage provided by Ellis Brett Pond, the gate remains fully open under normal conditions and from the start of the flood event until the time when flows start to significantly increase. At this point, the gate will raise to an elevation that will allow for the detention of these higher runoff inflow volumes by restricting the opening height of the primary spillway openings. The gate will remain in this position until inflow begins to recede and the gate can slowly start to open and release detained flows to the downstream river reach in a controlled manner. The height that the gate will be raised to in each of the spillway openings varies for each flood event analyzed. This gate height was determined through an iterative process such that the peak water surface elevation within

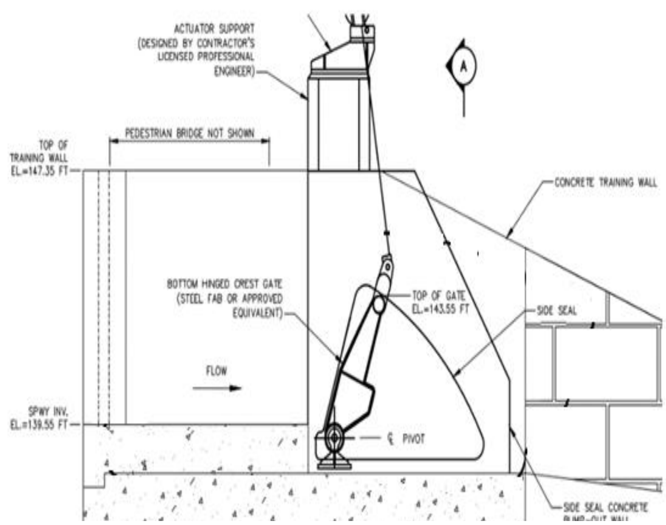


Figure 8-4. Ellis Brett Proposed Bottom-Hinged Spillway Gate

Ellis Brett (for each flood event) did not come within 18 inches of the dam's crest or within 6 inches of the dam's overflow spillway crest.

Based on the results of our analysis, it appears that installing a gate within the primary spillway of Ellis Brett Pond will have the following impacts to downstream water surface elevations during the analyzed flood events:

Table 8-2. Ellis Brett Alternative EB-2 Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Elmwood Avenue to Prospect Street	-1.0	-0.7	0.0	0.0	0.0
Prospect Street to Pleasant Street	-1.1	-0.7	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	-1.1	-0.9	-0.1	0.0	0.0
Moraine Street Conduit to Ash Street	-0.8	-0.7	-0.3	0.0	0.0
Ash Street to Belmont Avenue	-0.8	-0.4	-0.1	0.0	0.0
Belmont Avenue to Carleton Street	-0.6	-0.3	-0.1	0.0	0.0
Carleton Street to No. Arlington Culvert	-0.9	-0.5	-0.1	0.0	0.0
Belmont Street (123) to Warren Avenue	-0.6	-0.3	0.0	0.0	0.0
Warren Avenue to Allen Street	-0.6	-0.2	0.0	0.0	0.0
Allen Street to White Avenue	-0.4	-0.1	-0.1	0.0	0.0
White Avenue to Railroad Bridge	-0.5	-0.2	-0.1	0.0	0.0
Railroad Bridge to Otis Street	-0.4	-0.1	-0.1	0.0	0.0
Otis Street to Grove Street	-0.3	-0.2	-0.1	0.0	0.0
Grove Street to Pine Avenue	-0.3	-0.1	-0.1	0.0	0.0
Pine Avenue to Perkins Avenue	-0.4	-0.1	-0.1	0.0	0.0
Perkins Avenue to Plain Street	-0.4	-0.2	-0.1	0.0	0.0
Plain Street to Sargent's Way	-0.2	-0.1	0.0	0.0	0.0
Sargent's Way to WWTF/K-Mart Plaza	-0.2	-0.1	0.0	0.0	0.0

Notes:

1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

As reflected in the table above, detaining flows in Ellis Brett Pond will result in downstream flood elevation reductions throughout Salisbury Brook for the 2- through 10-year flood events. Although there were minor reductions noted downstream for the 50-year flood, such reductions were insignificant.

Failure of this alternative to provide significant flood reduction for larger storms is likely due to two key factors:

- The existing storage volume available within Ellis Brett is adequate to support reductions in downstream flood elevations for the 2- through 10-year flood events, but is not large enough to support meaningful flood reductions for the 50- through 500-year flood events.
- The flow contribution entering from Trout Brook downstream of Ellis Brett Pond is relatively large in respect to flows being conveyed by Salisbury Brook and will therefore diminish any

potential flood storage benefits provided by Ellis Brett Pond throughout the Salisbury Plain River.

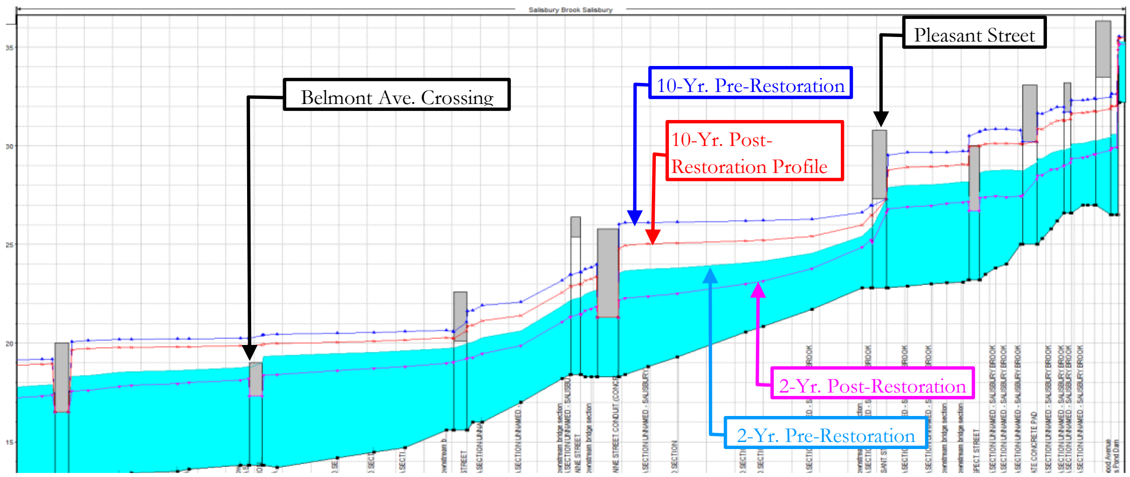


Figure 8-5. Alternative EB-2 Pre- Versus Post-Improvement 2- and 10-Year Water Surface Elevation Profiles Comparison (from Elmwood Avenue to Spring Street)

8.1.3 Alternative EB-3 Summary & Hydraulic Analysis Results

This alternative combines the improvements proposed for Alternatives EB-1 and EB-2. It proposes the clearing and excavation of a 9.8-acre area primarily to the north of Ellis Brett Pond that exists above the pond's normal water surface elevation in addition to the installation of a bottom-hinged (remotely controlled) crest gate within the dam's primary spillway openings. Based on the results of our analysis, it appears that this alternative will have the following impacts to downstream water surface elevations during the analyzed flood events:

Table 8-3. Ellis Brett Alternative EB-3 Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Elmwood Avenue to Prospect Street	-1.3	-0.9	-0.1	0.0	0.0
Prospect Street to Pleasant Street	-1.4	-1.0	-0.1	0.0	0.0
Pleasant Street to Moraine Street Conduit	-1.5	-1.4	-0.3	-0.2	-0.1
Moraine Street Conduit to Ash Street	-1.3	-1.0	-0.8	-0.6	-0.1
Ash Street to Belmont Avenue	-1.3	-0.7	-0.3	-0.3	-0.1
Belmont Avenue to Carleton Street	-1.1	-0.9	-0.3	-0.1	-0.1
Carleton Street to No. Arlington Culvert	-1.1	-1.1	-0.3	0.0	-0.1
Belmont Street (123) to Warren Avenue	-0.8	-0.5	-0.2	-0.1	-0.1
Warren Avenue to Allen Street	-0.8	-0.4	-0.2	-0.1	0.0
Allen Street to White Avenue	-0.5	-0.2	-0.7	-0.1	0.0
White Avenue to Railroad Bridge	-0.7	-0.3	-0.8	-0.2	0.0
Railroad Bridge to Otis Street	-0.6	-0.2	-0.4	-0.2	-0.1
Otis Street to Grove Street	-0.5	-0.3	-0.2	-0.1	-0.1

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Grove Street to Pine Avenue	-0.5	-0.2	-0.1	0.0	0.0
Pine Avenue to Perkins Avenue	-0.7	-0.3	-0.1	0.0	0.0
Perkins Avenue to Plain Street	-0.5	-0.3	-0.1	-0.1	0.0
Plain Street to Sargent's Way	-0.4	-0.2	-0.1	-0.1	0.0
Sargent's Way to WWTF/K-Mart Plaza	-0.3	-0.1	0.0	0.0	0.0

Notes:

1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

As reflected in the table above and the results of analysis, detaining flows in Ellis Brett Pond via the installation of a gate in combination with increased storage due to excavation will primarily result in downstream flood elevation reductions throughout the Salisbury Brook portion of the system for the 2- through 10-year flood events. Unlike the previous alternatives for Ellis Brett, however, this alternative will also provide measurable flood reductions that carry throughout the Salisbury Plain River section of the system during the 2- through 10-year flood events. It will also provide some appreciable reductions in 50-year flood elevations within the sections of the Salisbury Brook between Moraine Street and North Arlington Street and Allen Street to Otis Street.

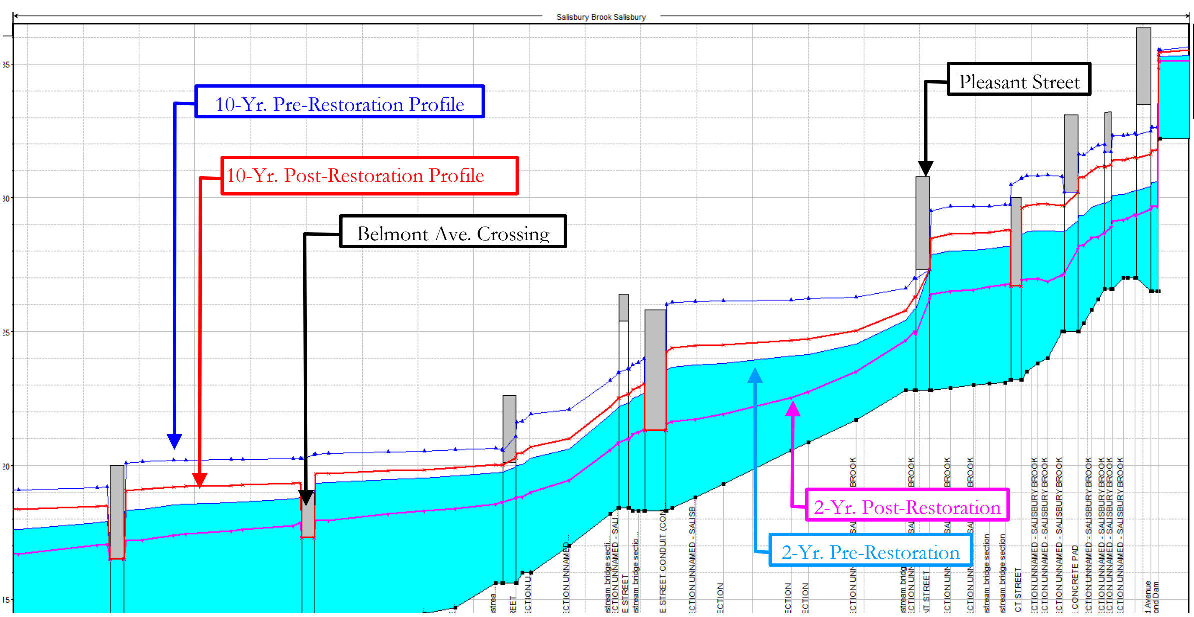


Figure 8-6. Alternative EB-3 Pre- Versus Post-Improvement 2- and 10-Year Water Surface Elevation Profiles Comparison (from Elmwood Avenue to Spring Street)

8.1.4 Ellis Brett Pond Alternative Cost/Benefit Analysis Summary

A qualitative cost/benefit evaluation table has been provided in this section to serve as a preliminary decision-making tool for evaluating the overall benefits and costs associated with each Ellis Brett Pond flood reduction alternative. The table has been populated with order of magnitude costs, flood reduction benefit summaries, and qualitative benefit-to-cost ratings for each alternative considered (in respect to the other alternatives). The benefit-to-cost rating is based on a scale of "low" to "high," with "high" being the most advantageous and "low" being the most disadvantageous in terms of flood reductions with respect to costs. The ratings also consider the amount of flood elevation reduction that occurs in locations that have been identified as areas of frequent residential and/or commercial flooding and where roadway closures have been previously reported due to bridge/roadway inundation.

Table 8-4. Ellis Brett Alternatives Flood Reduction Summary and Qualitative Benefit-to-Cost Score

Concept Alternative	Average Flood Reduction Benefits	Opinion of Cost	B/C Score
Ellis Brett EB-1	**2-Year Flood:** • Reduces flood elevations between Elmwood Avenue and Pleasant Street by 2" to 3" • Reduces flood elevations between Pleasant Street and Belmont Avenue by 5" to 6" • *Eliminates Overtopping of Belmont Avenue Bridge* • Reduces flood elevations between Belmont Avenue and Newbury Street by 3" to 4" • Reduces flood elevations between Belmont Street (Route 123) and Otis Street by 3" to 4"	$2.6-$5.1M	Low
	10- Year Flood: • Reduces flood elevations between Elmwood Avenue and Pleasant Street by 3" to 4" • Reduces flood elevations between Pleasant Street and Belmont Avenue by 5" to 6" • *Eliminates Overtopping of Spring Street Bridge* • Reduces flood elevations between Belmont Avenue and Newbury Street by 3" to 4" • Reduces flood elevations between Route 123 and Warren Avenue by 3" to 4" • Reduced flood elevations between Warren Avenue and Otis Street by 1" to 3"		
	50-Year Flood: • Reduces flood elevations between Pleasant Street and Moraine Conduit by 2" to 3" • Reduces flood elevations between Moraine Conduit and Belmont Avenue by 3" to 6" • Reduces flood elevations between Belmont Avenue and Newbury Street by 2" to 3" • Reduces flood elevations between Allen Street to Otis Street by 4" to 6" • *Eliminates Overtopping of White Street Bridge* • Reduced flood elevations between Otis and Grove Streets by 2" to 3"		
	100-Year: • Reduces flood elevations between Pleasant Street and Moraine Conduit by 2" to 3" • Reduces flood elevations between Moraine Conduit and Belmont Avenue by 4" to 6" • Reduces flood elevations between White Avenue to Otis Street by 2" to 3"		
	500-Year: Insignificant Flood Reductions		
Ellis Brett EB-2	**2-Year Flood:** • Reduces flood elevations between Elmwood Avenue and Pleasant Street by 12"-15" • Reduces flood elevations between Pleasant Street and Belmont Avenue by 9" to 12" • *Eliminates Overtopping of Belmont Avenue Bridge* • Reduces flood elevations between Belmont Avenue and Newbury Street by 7" to 12" • Reduces flood elevations between Belmont Street (Route 123) and Otis Street by 5" to 7" • Reduces flood elevations between Otis and Plain Streets by 4" to 5" • Reduces flood elevations between Plain Street and City Boundary by 2" to 3"	$400K-$900K (Excl. Annual Maint. and Elect. Costs)	High
	10- Year Flood: • Reduces flood elevations between Elmwood Avenue and Pleasant Street by 8" to 9"		

Concept Alternative	Average Flood Reduction Benefits	Opinion of Cost	B/C Score
	• *Eliminates Overtopping of Prospect Street Bridge* • Reduces flood elevations between Pleasant Street and Belmont Avenue by 5" to 11" • *Eliminates Overtopping of Spring Street Bridge* • Reduces flood elevations between Belmont Avenue and Newbury Street by 4" to 6" • Reduces flood elevations between Route 123 and Warren Avenue by 3" to 4" • Reduced flood elevations between Warren Avenue and Allen Street by 2" to 3" **50-Year Flood:** • Reduces flood elevations between Moraine Conduit and Ash Street by 3" to 4" **100-Year and 500-Year:** Insignificant Flood Reductions		
Ellis Brett EB-3	**2-Year Flood:** • Reduces flood elevations between Elmwood Avenue and Pleasant Street by 12" to 15" • Reduces flood elevations between Pleasant Street and Belmont Avenue by 15" to 18" • *Eliminates Overtopping of Belmont Avenue Bridge* • Reduces flood elevations between Belmont Avenue and Newbury Street by 12" to 13" • Reduces flood elevations between Belmont Street (Route 123) and Otis Street by 6" to 10" • Reduces flood elevations between Otis and Plain Streets by 6" to 8" • Reduces flood elevations between Plain Street and City Boundary by 4" to 5" **10- Year Flood:** • Reduces flood elevations between Elmwood Avenue and Pleasant Street by 11" to 12" • Reduces flood elevations between Pleasant Street and Belmont Avenue by 8" to 18" • *Eliminates Overtopping of Prospect Street Bridge* • *Eliminates Overtopping of Spring Street Bridge* • Reduces flood elevations between Belmont Avenue and Newbury Street by 11" to 13" • Reduces flood elevations between Route 123 and Warren Avenue by 5" to 6" • Reduced flood elevations between Warren Avenue and Allen Street by 5" to 6" • Reduces flood elevation between Allen Street to Sargent's Way by 2" to 4" **50-Year Flood:** • Reduces flood elevations between Pleasant Street and Moraine Conduit by 4" to 5" • Reduces flood elevations between Moraine Conduit and Belmont Avenue by 4" to 10" • Reduces flood elevations between Belmont Avenue and Newbury Street by 3" to 4" • Reduces flood elevations between Route 123 and Allen Street by 2" to 3" • Reduces flood elevations between Allen Street to Otis Street by 5" to 10" • *Eliminates Overtopping of White Street Bridge* • Reduced flood elevations between Otis and Grove Streets by 2" to 3" **100-Year:** • Reduces flood elevations between Pleasant Street and Moraine Conduit by 2" to 3" • Reduces flood elevations between Moraine Conduit and Belmont Avenue by 4" to 7" • Reduces flood elevations between White Avenue to Otis Street by 2" to 3" **500-Year:** Insignificant Flood Reductions	$2.9-$5.6M	Medium

Full-size water surface profiles, hydraulic analysis summary data, and more detailed breakdowns of order of magnitude opinions of cost for each of the Ellis Brett alternatives are provided in **Appendix D**. It is important to note that the caveats discussed above in Section 1.1.1 with respect to the Ellis Brett Pond excavation alternatives may alter the cost-benefit analysis and expected benefits.

8.2 Cross Pond Excavation & Ecological Enhancement

Figure 8-7. Aerial View of Cross Pond (Present-Day Conditions)

Cross Pond currently has a normal pool surface area of approximately 1.5 acres and holds approximately 4,600 cubic yards (or 2.9 acre-feet) of water under normal conditions. The pond is impounded by Elmwood Avenue, which functions as a dam embankment, and consists of a horseshoe-shaped spillway. The approximate crest elevation of the spillway is El. 134.2 feet (NAVD88); the approximate crest of the dam is El. 136.4 feet (NAVD88). The maximum storage volume of the pond, below El. 136.4 feet, is approximately 15,600 cubic yards (or 9.7 acre-feet). To put this into perspective, this is approximately five times less than the maximum storage volume provided by Ellis Brett Pond under current conditions. It should also be noted that although the impoundment does have a 42-inch diameter low-flow outlet, it is reported to be inoperable. As a result, the spillway crest primarily controls the normal water surface elevation of the impoundment.

In spite of Cross Pond's relatively small size and low storage volume, it is still located in the upper part of Salisbury Brook and could potentially provide flood reduction benefits downstream during flood events. As a result, the following three alternatives were developed to assess the flood reduction benefits that could be realized downstream if flood storage benefits at Cross Pond were maximized.

- Cross Pond Alternative 1 (CP-1) – Install a notch within the spillway, or alternatively replace the pond's inoperable low-flow outlet with a new low-flow outlet, to lower the normal water surface elevation of Cross Pond from El. 134.2 feet (NAVD88) to El. 132.2 feet (NAVD88). This will increase the storage volume of the pond above the normal water surface elevation by approximately 4,600 cubic yards (or approximately 2.9 acre-feet).
- Cross Pond Alternative 2 (CP-2) – Perform excavation of a section of the vacant (wooded) area immediately to the northwest of Cross Pond above the pond's existing normal water level (El. 134.2 feet) to increase the pond's maximum storage volume above the existing pond's normal water surface elevation by approximately 1,700 cubic yards (or approximately 1.1 acre-feet).
- Cross Pond Alternative 3 (CP-3) – Combine improvements from Cross Pond Alternatives CP-1 and CP-2 to increase the total storage volume of the pond by approximately 11,100 cubic yards (or approximately 2.9 acre-feet) above the existing pond's normal water surface elevation.

8.2.1 Alternative CP-1 Summary & Hydraulic Analysis Results

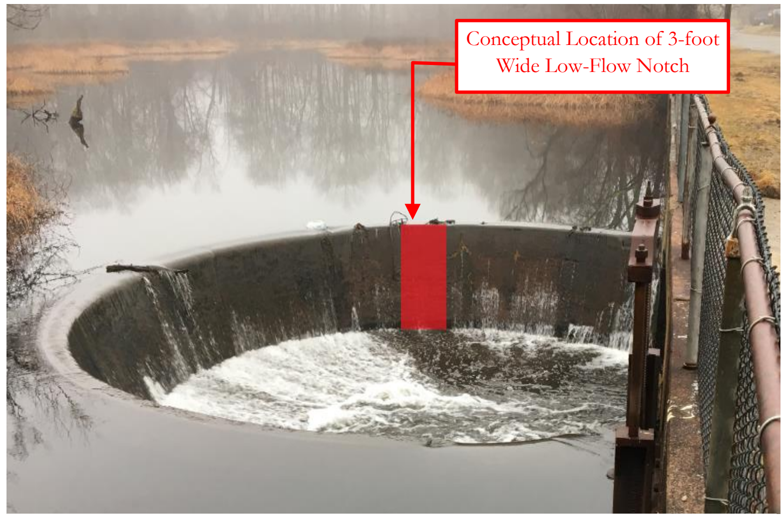


Figure 8-8. Proposed Cross Pond Low-Flow Spillway Notch

This alternative could include either the installation of a low-flow notch within the dam's existing spillway or the replacement of the dam's 42-inch diameter low-flow outlet with a new, operable low-flow outlet. Both options would result in lowering of the normal or initial water surface elevation of Cross Pond by approximately two feet to El. 132.2± feet (NAVD88) in order to take advantage of the existing volume of flood storage that is available within the impoundment. The new low-flow outlet option would entail the installation of a 42-inch diameter low-flow outlet set to an invert of 130.2 feet (NAVD88) that would be operated in a fully open position prior to and during the flood events analyzed. The low-flow notch option would entail the installation of a 3-foot wide low-flow notch within the dam's primary spillway also set to an invert of 130.2 feet (NAVD88). Because it is understood that the installation of a low-flow outlet would require human intervention prior to or during flood events, the installation of a low-flow notch in the existing spillway was assumed to be the preferred option for this alternative and for purposes of this analysis.

Based on the results of our analysis, it appears that installing a low-flow notch at Cross Pond to detain flows in Cross Pond will not result in appreciable downstream flood elevation reductions for the storm events analyzed. All reductions were limited to 0.02 feet or less throughout the river system (**Table 8-5**). This indicates that the existing storage volume that is available within Cross Pond is not significant enough to support meaningful downstream flood reductions for any of the storm events analyzed.

Table 8-5. Cross Pond Alternative CP-1 Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Elmwood Avenue to Prospect Street	0.0	0.0	0.0	0.0	0.0
Prospect Street to Pleasant Street	0.0	0.0	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	0.0	0.0	0.0	0.0	0.0
Moraine Street Conduit to Ash Street	0.0	0.0	0.0	0.0	0.0
Ash Street to Belmont Avenue	0.0	0.0	0.0	0.0	0.0
Belmont Avenue to Carleton Street	0.0	0.0	0.0	0.0	0.0
Carleton Street to No. Arlington Culvert	0.0	0.0	0.0	0.0	0.0
Belmont Street (123) to Warren Avenue	0.0	0.0	0.0	0.0	0.0
Warren Avenue to Allen Street	0.0	0.0	0.0	0.0	0.0

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Allen Street to White Avenue	0.0	0.0	0.0	0.0	0.0
White Avenue to Railroad Bridge	0.0	0.0	0.0	0.0	0.0
Railroad Bridge to Otis Street	0.0	0.0	0.0	0.0	0.0
Otis Street to Grove Street	0.0	0.0	0.0	0.0	0.0
Grove Street to Pine Avenue	0.0	0.0	0.0	0.0	0.0
Pine Avenue to Perkins Avenue	0.0	0.0	0.0	0.0	0.0
Perkins Avenue to Plain Street	0.0	0.0	0.0	0.0	0.0
Plain Street to Sargent's Way	0.0	0.0	0.0	0.0	0.0
Sargent's Way to WWTF/K-Mart Plaza	0.0	0.0	0.0	0.0	0.0
Notes: 1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River. 2. All water surface elevation (WSE) changes within table are in feet.					

8.2.2 Alternative CP-2 Summary & Hydraulic Analysis Results

This alternative proposes the clearing and excavation of a 1.9-acre area primarily to the northwest of the normally inundated section of Cross Pond that exists above the pond's normal water surface elevation. Unlike Alternative CP-1, this alternative assumes that the dam's existing primary spillway will remain unchanged and that the existing low-flow outlet will remain inoperable.

As a result, this alternative does not propose the lowering of the pond's normal water surface elevation and will result solely in the removal of approximately 1,700 cubic yards of material between El. 134.2± (NAVD88) and El. 136.4± (NAVD88).

Figure 8-9. Alternative CP-2 Proposed Clearing and Excavation Limits

Based on the results of our analysis, it appears that increasing the storage volume of Cross Pond (without changes to the primary spillway) will also have insignificant reductions to downstream water surface elevations during the analyzed flood events as shown in **Table 8-6**.

Table 8-6. Cross Pond Alternative 2 Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Elmwood Avenue to Prospect Street	0.0	0.0	0.0	0.0	0.0
Prospect Street to Pleasant Street	0.0	0.0	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	0.0	0.0	0.0	0.0	0.0
Moraine Street Conduit to Ash Street	0.0	0.0	0.0	0.0	0.0
Ash Street to Belmont Avenue	0.0	0.0	0.0	0.0	0.0
Belmont Avenue to Carleton Street	0.0	0.0	0.0	0.0	0.0
Carleton Street to No. Arlington Culvert	0.0	0.0	0.0	0.0	0.0
Belmont Street (123) to Warren Avenue	0.0	0.0	0.0	0.0	0.0
Warren Avenue to Allen Street	0.0	0.0	0.0	0.0	0.0
Allen Street to White Avenue	0.0	0.0	0.0	0.0	0.0
White Avenue to Railroad Bridge	0.0	0.0	0.0	0.0	0.0
Railroad Bridge to Otis Street	0.0	0.0	0.0	0.0	0.0
Otis Street to Grove Street	0.0	0.0	0.0	0.0	0.0
Grove Street to Pine Avenue	0.0	0.0	0.0	0.0	0.0
Pine Avenue to Perkins Avenue	0.0	0.0	0.0	0.0	0.0
Perkins Avenue to Plain Street	0.0	0.0	0.0	0.0	0.0
Plain Street to Sargent's Way	0.0	0.0	0.0	0.0	0.0
Sargent's Way to WWTF/K-Mart Plaza	0.0	0.0	0.0	0.0	0.0

Notes:
1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

8.2.3 Alternative CP-3 Summary & Hydraulic Analysis Results

This alternative combines the improvements proposed for Cross Pond Alternatives CP-1 and CP-2. Installing a notch in the primary spillway will result in the lowering of the normal water surface elevation from El. 134.2 feet (NAVD88) to El. 132. 2 feet (NAVD88). This combined with the clearing and expansion of the footprint of the pond by approximately 1.9 acres will result in an increase in total flood storage of approximately 11,100 cubic yards between El. 132.2± (NAVD88) and El. 136.2± (NAVD88). It also will allow for an increase in the width of

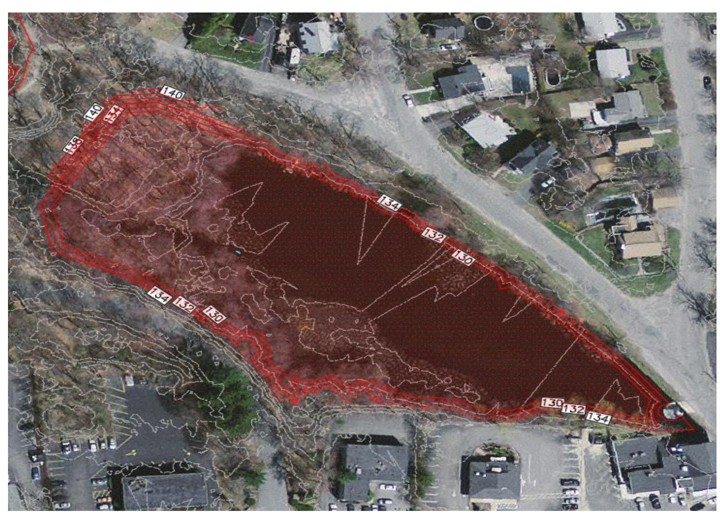


Figure 8-10. Alternative CP-3 Proposed Clearing and Excavation Limits

the low-flow notch from 3 feet to 8 feet as compared to Cross Pond Alternative CP-1. The width of the notch was determined through an iterative process where the notch width was varied from 3.0 feet to 10.0 feet. The 8-foot width selected represents the notch width that resulted in the greatest average reductions in downstream flood elevations.

To limit the growth of vegetation beneath the normal pond elevation and to promote aquatic habitat throughout the proposed limits of excavation, additional excavation could also be performed to El. 130.2 feet (NAVD88) in order to maintain a constant stand of water throughout the pond below El. 132.2 feet (NAVD88). This volume of approximately 8,600 cubic yards, however, would not increase the amount of storage available during floods since it is below the pond's normal water surface elevation and will be occupied by water at the onset of the flood events.

Based on the results of our analysis, it appears that this alternative will not result in appreciable downstream flood elevation reductions for the storm events analyzed. Although minor reductions were noted throughout Salisbury Brook for this alternative, all reductions were limited to 0.02 feet or less throughout the river system.

Table 8-7. Cross Pond Alternative 3 Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Elmwood Avenue to Prospect Street	-0.1	0.0	0.0	0.0	0.0
Prospect Street to Pleasant Street	-0.1	0.0	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	-0.1	-0.1	0.0	0.0	0.0
Moraine Street Conduit to Ash Street	-0.1	0.0	0.0	0.0	0.0
Ash Street to Belmont Avenue	-0.1	0.0	0.0	0.0	0.0
Belmont Avenue to Carleton Street	-0.1	0.0	0.0	0.0	0.0
Carleton Street to No. Arlington Culvert	-0.1	-0.1	0.0	0.0	0.0
Belmont Street (123) to Warren Avenue	-0.1	-0.1	0.0	0.0	0.0
Warren Avenue to Allen Street	-0.1	-0.1	0.0	0.0	0.0
Allen Street to White Avenue	-0.1	-0.1	-0.1	0.0	0.0
White Avenue to Railroad Bridge	-0.1	-0.1	-0.1	0.0	0.0
Railroad Bridge to Otis Street	-0.1	-0.1	-0.1	0.0	0.0
Otis Street to Grove Street	0.0	0.0	0.0	0.0	0.0
Grove Street to Pine Avenue	0.0	0.0	0.0	0.0	0.0
Pine Avenue to Perkins Avenue	0.0	0.0	0.0	0.0	0.0
Perkins Avenue to Plain Street	0.0	0.0	0.0	0.0	0.0
Plain Street to Sargent's Way	0.0	0.0	0.0	0.0	0.0
Sargent's Way to WWTF/K-Mart Plaza	0.0	0.0	0.0	0.0	0.0

Notes:

1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

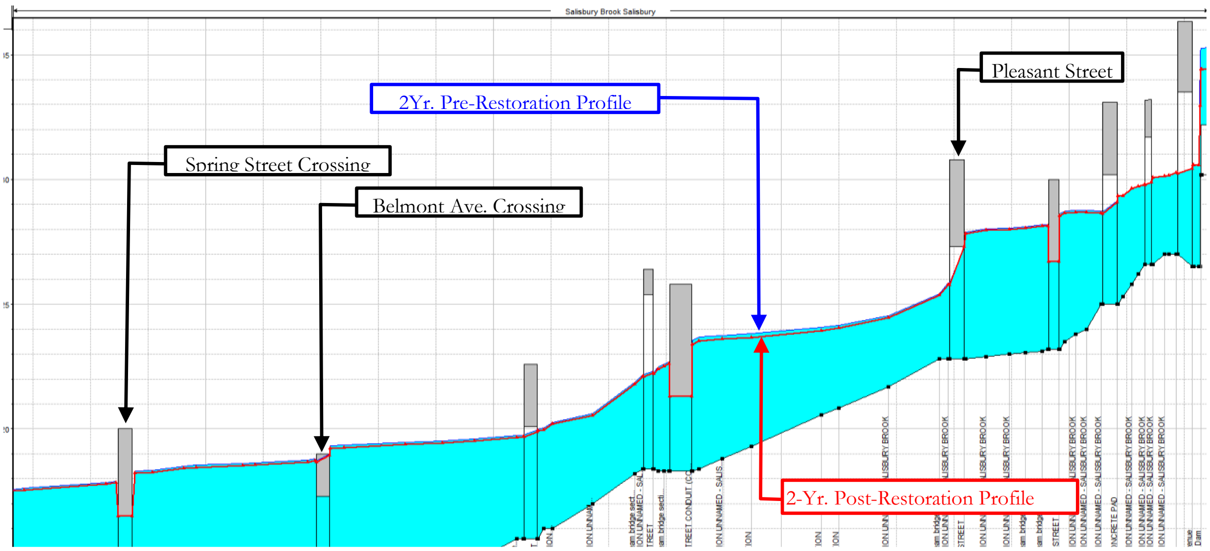


Figure 8-11. Alternative CP-3 Pre- Versus Post-Improvement 2-Year Water Surface Elevation Profile Comparison (from Elmwood Avenue to Spring Street)

8.2.4 Cross Pond Alternative Cost/Benefit Analysis Summary

A qualitative cost/benefit evaluation table has been provided in this section to serve as a preliminary decision-making tool for evaluating the overall benefits and costs associated with each flood Cross Pond flood reduction alternative. The table has been populated with order of magnitude costs, flood reduction benefit summaries (for each flood event analyzed), and qualitative benefit-to-cost ratings for each alternative considered (in respect to the other alternatives).

Table 8-8. Cross Pond Alternatives Flood Reduction Summary and Qualitative Benefit-to-Cost Score

Conceptual Alternative	Average Flood Reduction Benefits	Opinion of Cost	B/C Score
Cross Pond Alt.1	**2-, 10-, 50-, 100-, and 500-Year Floods:** Insignificant Flood Reductions	$200K-$500K	Low
Cross Pond Alt. 2	**2-, 10-, 50-, 100-, and 500-Year Floods:** Insignificant Flood Reductions	$600K-$1.1M	Low
Cross Pond Alt. 3	**2-Year Flood:** • Reduces flood elevations between Elmwood Avenue and Otis Street by 1" to 2" **10- Year Flood:** • Reduces flood elevations between Elmwood Avenue and Otis Street by 1" to 2" **50-Year Flood:** • Reduces flood elevations between Pleasant Street and Moraine Conduit by 1" to 2" • Reduces flood elevations between Carleton Street and Otis Street by 1" to 2" **100-Year and 500-Year Floods:** Insignificant Flood Reductions	$1.5-$2.8M	Low

Full-size water surface profiles, hydraulic analysis summary data, and more detailed breakdowns of order of magnitude opinions of cost for each of the Cross Pond alternatives are provided in **Appendix D**.

8.3 Floodplain Restoration of Undeveloped Parcels

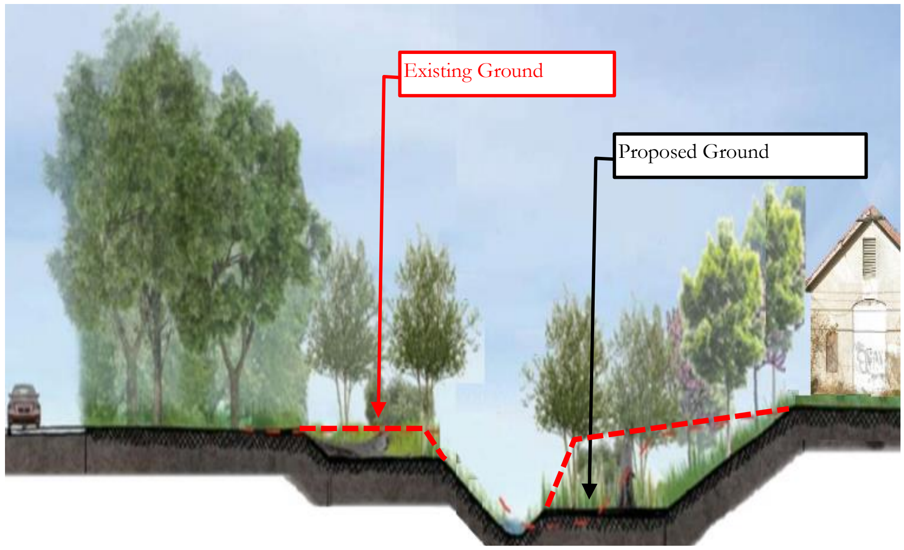


Figure 8-12. Typical Floodplain Restoration Section (Modified by Fuss & O'Neill from VDOT Pike's Branch Stream Restoration Presentation, 2018)

Several undeveloped portions of City- or privately-owned parcels that are located directly along the Salisbury Brook and Salisbury Plain River were identified as potential locations where floodplain restoration could assist in reducing flood levels at bridges and in areas most susceptible to frequent flooding as identified as part of Task 2.2. Floodplain restoration techniques considered at these locations included: increasing floodplain storage in channel overbank locations (i.e. storage above the estimated bankfull or normal water surface elevation) through excavation; widening the river channel in areas where development has resulted in a significant hydraulic constriction or encroachment into the river's natural floodplain; and stream daylighting. The areas that were initially identified and analyzed for potential floodplain restoration for this alternative included:

Figure 8-13. Potential Floodplain Restoration Areas between Prospect and Moraine Streets

- Prospect Street to Moraine Street – floodplain restoration of two undeveloped areas (on river left) between Prospect Street and Moraine Street. Approximately 3,900 cubic yards of additional floodplain storage was proposed between El. 126 to El. 132 (NAVD88) and approximately 7,300 cubic yards between El. 122 and El. 126 feet (NAVD88).

- Belmont Avenue to Carleton Street – floodplain restoration of two undeveloped areas: one between Belmont Avenue and Spring Street and the other between Spring Street and Carleton Street. Approximately 1,400 cubic yards of additional floodplain storage was proposed between El. 115.5 to El. 118 (NAVD88) and approximately 10,500 cubic yards between El. 114 and El. 118 feet (NAVD88).

Figure 8-14. Potential Floodplain Restoration Areas between Belmont Avenue and Carleton Street

- Belmont Street (Route 123) to Warren Avenue: floodplain restoration of three undeveloped or vacant areas: the western section of Tannery Park along the Salisbury Brook, the undeveloped City-owned parking area (Parcel ID 058/014) along the river, and the southwestern section of Tartaglia Park. Approximately 3,330 cubic yards of increased floodplain storage was proposed between El. 100 to El. 114 (NAVD88) and approximately 4,900 cubic yards between El. 96 and El. 100 feet (NAVD88).

Figure 8-15. Potential Floodplain Restoration Areas between Belmont Street (Rt. 123) and Warren Avenue

- Warren Avenue to Railroad/Perkins Street - floodplain restoration of two undeveloped or vacant areas: Salisbury Park along both sides of the Salisbury Brook and the vacant undeveloped City-owned parking area (Parcel ID 135/072) between Montello Street and the Railroad. Approximately 14,400 cubic yards of additional floodplain storage was proposed between El. 93 to El. 100 (NAVD88). Additionally, the removal of the parking lot culvert will result in the daylighting of approximately 115 feet of river between Montello Street and the Railroad.

Figure 8-16. Potential Floodplain Restoration Areas between White Avenue and Perkins Street

- Perkins Street to Otis Street - floodplain restoration of undeveloped portions of private properties on both sides of a narrowed section of Salisbury Brook between Perkins Street and Otis Street where sharp bends in river alignment has resulted in erosion and sediment deposition. Approximately 720 cubic yards of additional floodplain storage was proposed between El. 86 to El. 92 (NAVD88).

Figure 8-17. Potential Floodplain Restoration Areas between Perkins Street and Otis Street

- Otis Street to Grove Street –resto ration of the undeveloped portion of one privately owned property (Parcel ID 136-006), and undeveloped portions of several City-owned properties (Parcel IDs 136-004, 136-017, 136-024, and 137-006) between Otis Street and Grove Street. Approximately 53,800 cubic yards of additional floodplain storage was proposed between El. 81 to El. 90 (NAVD88).
- Pine Avenue to Perkins Avenue – restoration of undeveloped portions of City-owned property Parcel ID125-010 and the lowering of its ballfields to increase floodplain storage. Restoration was also proposed on adjacent, undeveloped portions of private properties Parcel ID 125-009 (Walkover Commons) and Parcel IDs 126-014 & 126-015 (just south of Pine Avenue). Approximately 49,000 cubic yards of additional floodplain storage was proposed between El. 72 to El. 76 (NAVD88).

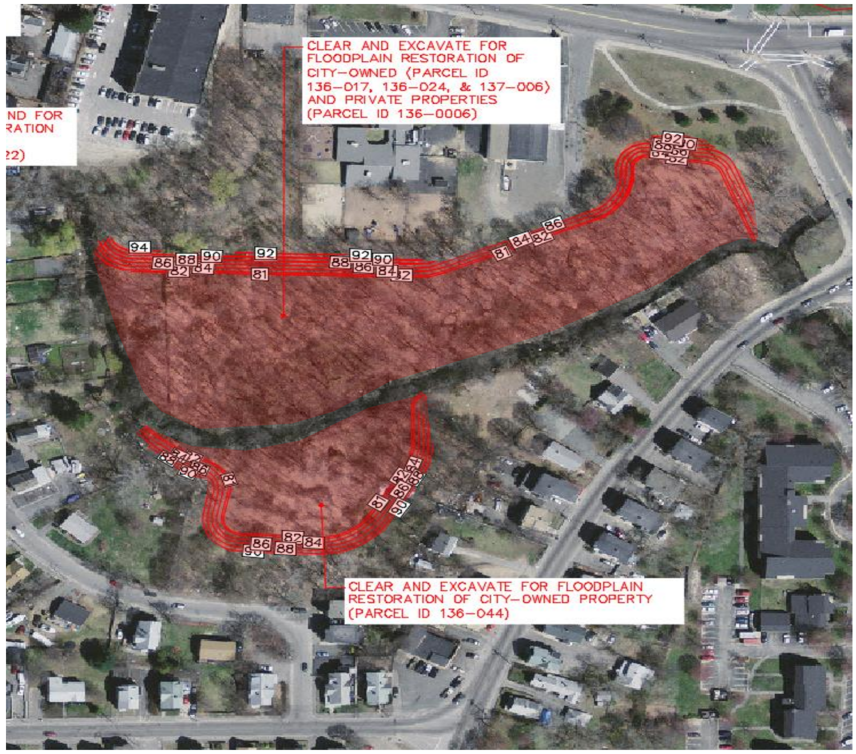


Figure 8-18. Potential Floodplain Restoration Areas between Otis Street and Grove Street

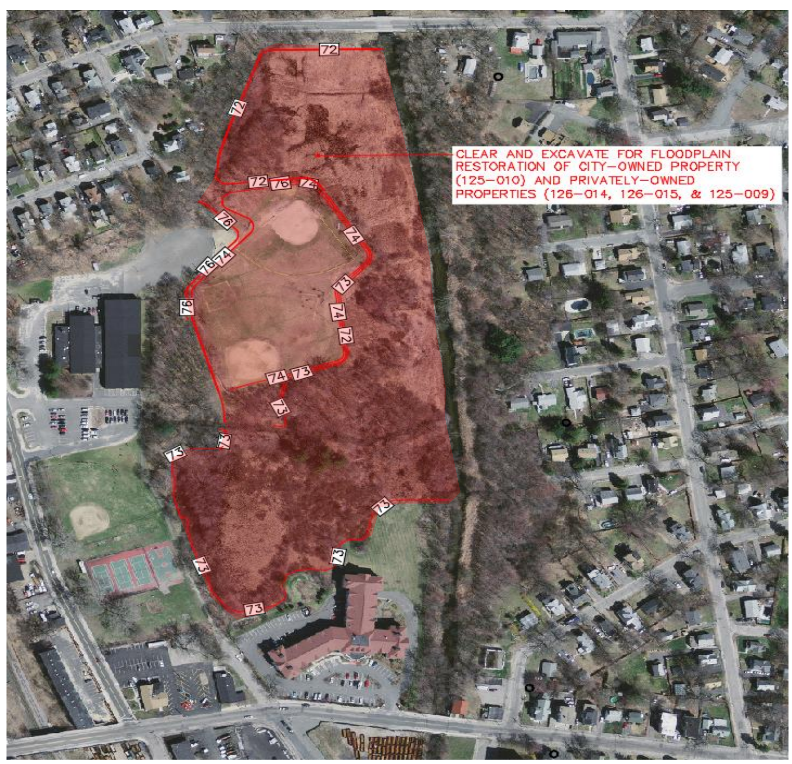


Figure 8-19. Potential Floodplain Restoration Areas between Otis Street and Grove Street

- Plain Street to Sargent's Way - floodplain restoration of three largely undeveloped, City-owned properties between Plain Street and Sargent's Way: Parcel ID 117-002, Parcel 118-064, and Parcel 118-186. Approximately 18,300 cubic yards of additional floodplain storage was proposed between El. 67 and El. 74 feet (NAVD88).
- Properties Downstream of Sargent's Way - floodplain restoration of undeveloped portions of three private properties located along the river: Parcel 118-19 0 (45 Industrial Boulevard), Parcel 118-172 (1724 Main Street), and Parcel 119-001 (1776 Main Street). This alternative proposes the widening of the floodplain immediately along the river and increases floodplain storage by approximately 22,500 cubic yards between El. 66 and El. 72 feet (NAVD88).

Figure 8-20. Potential Floodplain Restoration Areas between Plain Street and Sargent's Way

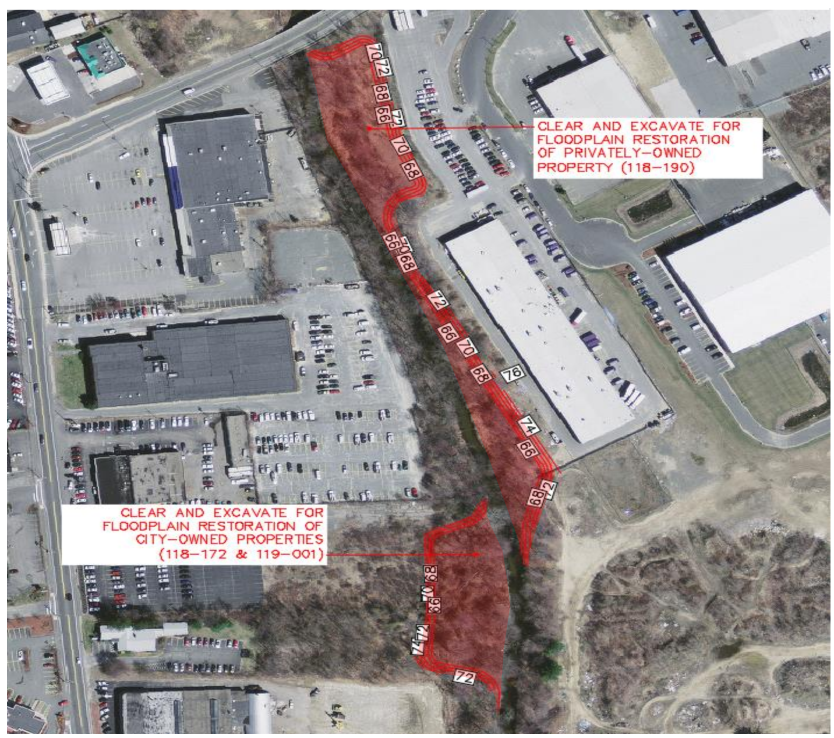


Figure 8-21. Potential Floodplain Restoration Areas Downstream of Sargent's Way

FUSS & O'NEILL

- Properties Across from the Brockton WWTP - floodplain restoration of undeveloped portions of two private properties located directly across the river from the Brockton Wastewater Treatment Plant (WWTP): Parcel 119-009 (2030 Main Street) and Parcel 119-011 (the adjacent property to the south). This alternative proposes the widening of the floodplain immediately along the river left and increases floodplain storage by approximately 11,000 cubic yards between El. 65 and El. 70 feet (NAVD88). The river cross sections in this location are constricted.

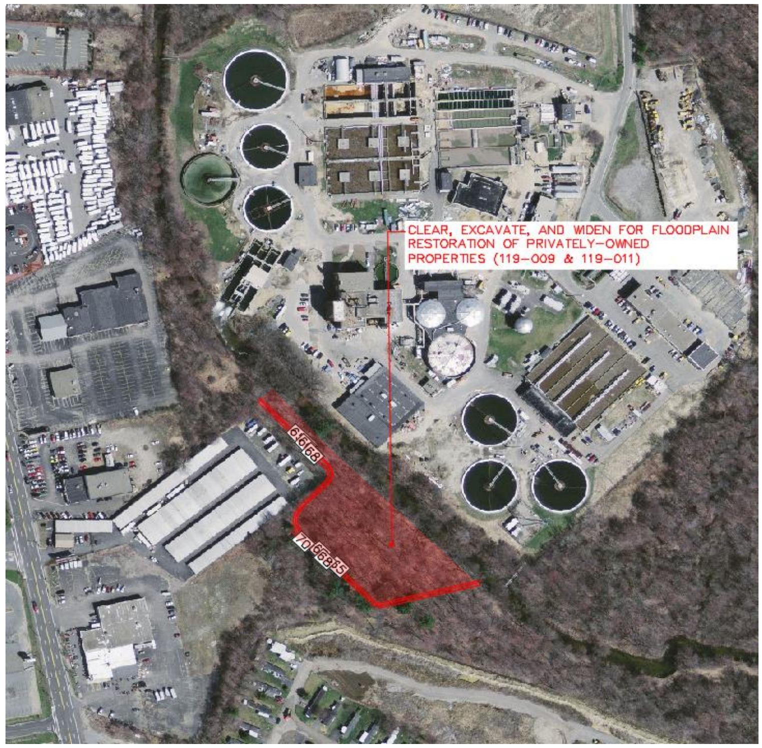


Figure 8-22. Potential Floodplain Restoration Areas Across from Brockton WWTP

Hydraulic (HEC-RAS) analyses for each of these restoration areas were initially performed to assess the relative benefits of floodplain restoration for the 2-, 10-, 50-, 100-, and 500-year flood events. The three alternatives that provided the most significant flood reduction benefits in terms of flood level reductions to frequently flooded areas along the river, adjacent roadways, and bridge crossings are described in more detail in the following sections. These three alternatives were:

- Restoration of areas between Warren Avenue and Railroad/Perkins Street; referred to herein as Alternative UP-1.
- Restoration of areas between Plain Street and Sargent's Way and just downstream of Sargent's Way; referred to herein as Alternative UP-2. Note that these two proposed areas were combined into one alternative because they each showed significant flood reductions as individual alternatives and their close proximity would facilitate treating them as a single project.
- Restoration of areas across from the Brockton WWTP; referred to herein as Alternative UP-3.

Refer to **Appendix D** for drawings that depict all locations considered for floodplain restoration.

8.3.1 Alternative UP-1 Summary & Hydraulic Analysis Results

This alternative proposed increasing floodplain storage within the Salisbury Park area as shown in **Figure 8-23** in addition to removing and restoring the adjacent City-owned vacant parking lot between Montello Street and Perkins Street (on Parcel 135-072). As part of the restoration of the vacant parking lot, the section of the parking lot that covers the Brook will be removed and approximately 115 linear feet of the Brook will be exposed to daylight. An approximate 9,200 cubic yard increase in floodplain storage along the Brook is proposed between El. 94 to El. 100 (NAVD 88) within the park area; an approximate 5,200 cubic yard increase in floodplain storage along the Brook is proposed between El. 93

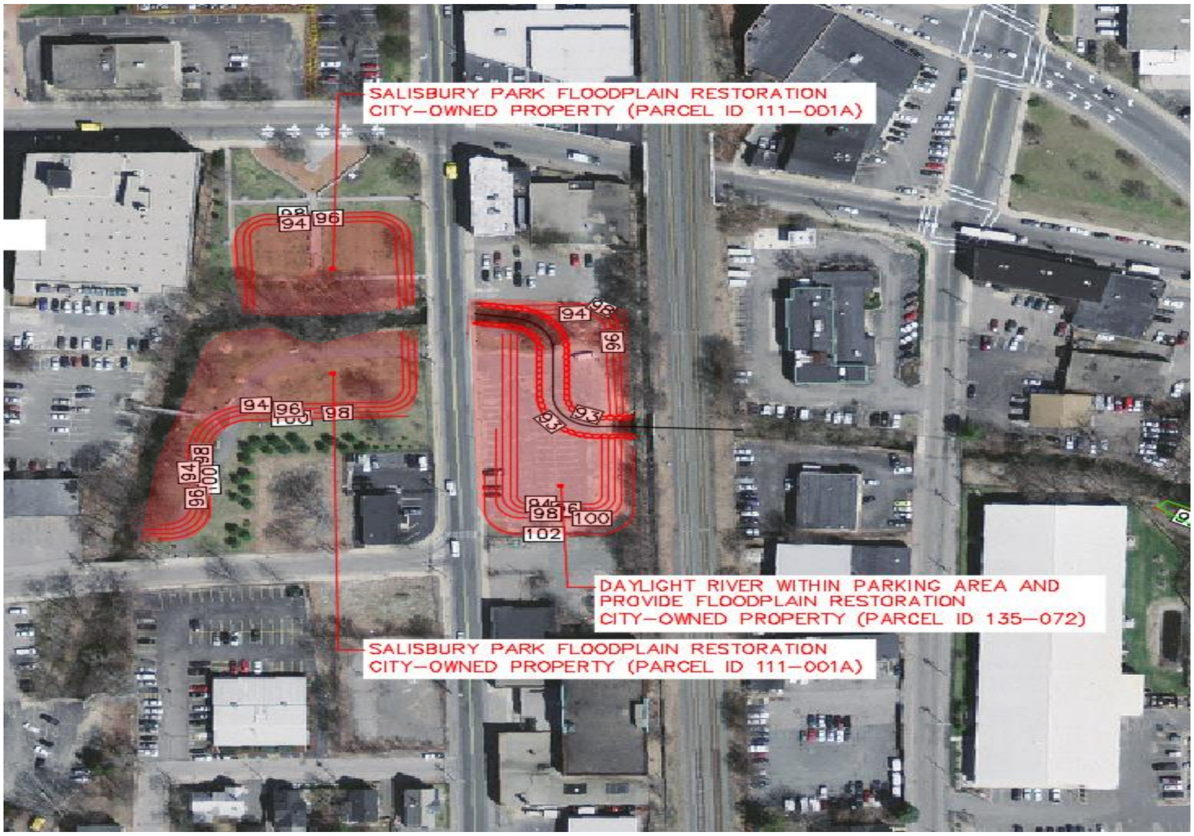


Figure 8-23. Potential Floodplain Restoration Areas between White Avenue and Perkins Street

to El. 100 (NAVD 88) within the area of the vacant parking lot.

Based on the results of our analysis, it appears that increasing floodplain storage at Salisbury Park and daylighting the channel will have the following impacts as reflected in **Table 8-9** during the analyzed flood events. Values shaded in light blue indicate locations where flood reductions will exceed two inches.

Table 8-9. Undeveloped/Vacant Parcel Alternative 1 (UP-1) Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Reduction	10-Year Avg. WSE Reduction	50-Year Avg. WSE Reduction	100-Year Avg. WSE Reduction	500-Year Avg. WSE Reduction
Elmwood Avenue to Prospect Street	0.0	0.0	0.0	0.0	0.0
Prospect Street to Pleasant Street	0.0	0.0	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	0.0	0.0	0.0	0.0	0.0
Moraine Street Conduit to Ash Street	0.0	-0.1	-0.1	-0.2	0.0
Ash Street to Belmont Avenue	-0.1	-0.1	-0.1	-0.2	-0.1
Belmont Avenue to Carleton Street	0.0	0.0	0.0	0.0	0.0

Location in River System	2-Year Avg. WSE Reduction	10-Year Avg. WSE Reduction	50-Year Avg. WSE Reduction	100-Year Avg. WSE Reduction	500-Year Avg. WSE Reduction
Carleton Street to No. Arlington Culvert	0.0	0.0	0.0	0.0	0.0
Belmont Street (123) to Warren Avenue	0.0	0.0	0.0	0.0	0.0
Warren Avenue to Allen Street	0.0	0.0	-0.1	0.0	+0.1
Allen Street to White Avenue	0.0	0.0	-0.5	-0.1	0.0
White Avenue to Railroad Bridge	-0.1	-0.1	-0.5	-0.2	-0.2
Railroad Bridge to Otis Street	0.0	0.0	-0.1	-0.1	-0.1
Otis Street to Grove Street	0.0	0.0	0.0	0.0	0.0
Grove Street to Pine Avenue	0.0	0.0	0.0	0.0	0.0
Pine Avenue to Perkins Avenue	0.0	0.0	0.0	0.0	0.0
Perkins Avenue to Plain Street	0.0	0.0	0.0	0.0	0.0
Plain Street to Sargent's Way	0.0	0.0	0.0	0.0	0.0
Sargent's Way to WWTP/K-Mart Plaza	0.0	0.0	0.0	0.0	0.0

Notes:
1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

The biggest reductions in flooding are seen during the 50-year storm event (**Figure 8-24**). For this event, the model indicates the removal of the culvert and provision of additional floodplain storage yields localized benefits of up to 0.5 feet reductions in the water surface elevation. This alternative also produces upstream flooding reductions up to Main Street and eliminates overtopping of the White Avenue Bridge during the 50-year flood event.

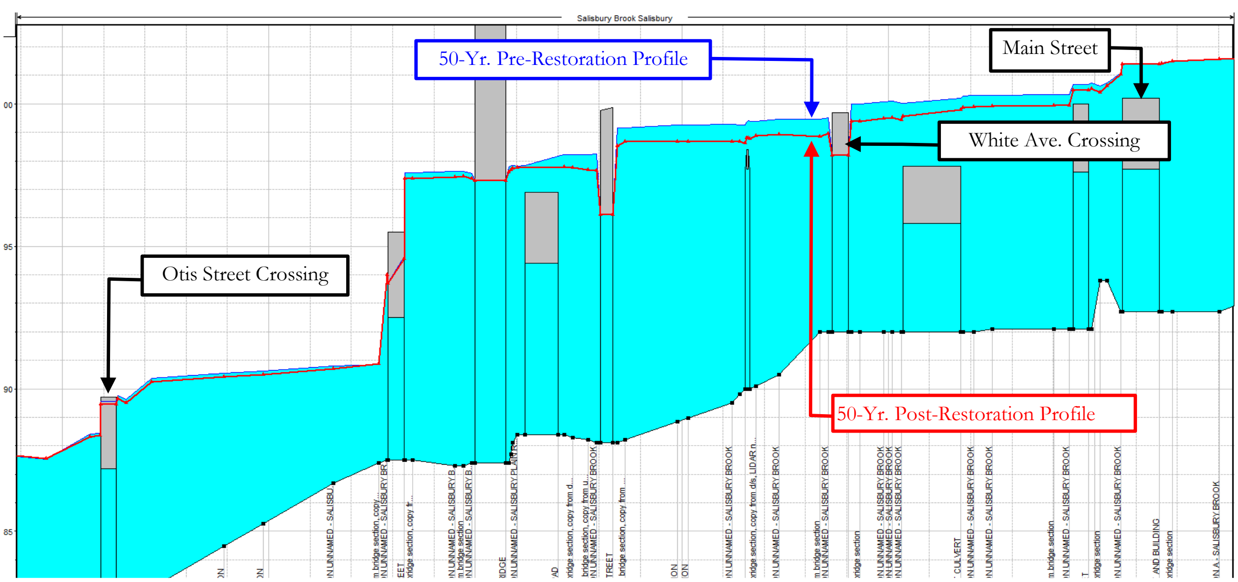


Figure 8-24. UP-1 Pre- Versus Post-Improvement 50-Year Water Surface Elevation Profile Comparison (from Main Street to Otis Street)

8.3.2 Alternative UP-2 Summary & Hydraulic Analysis Results

As part of this alternative, three undeveloped areas between Plain Street and Sargent's Way are proposed to be cleared and excavated in order to create additional floodplain storage (**Figure 8-25**). These parcels consist of City-owned, vacant properties. Excavation of material from these three areas will result in an increase of approximately 18,300 cubic yards of floodplain storage between El. 67 and El. 74 feet (NAVD88).

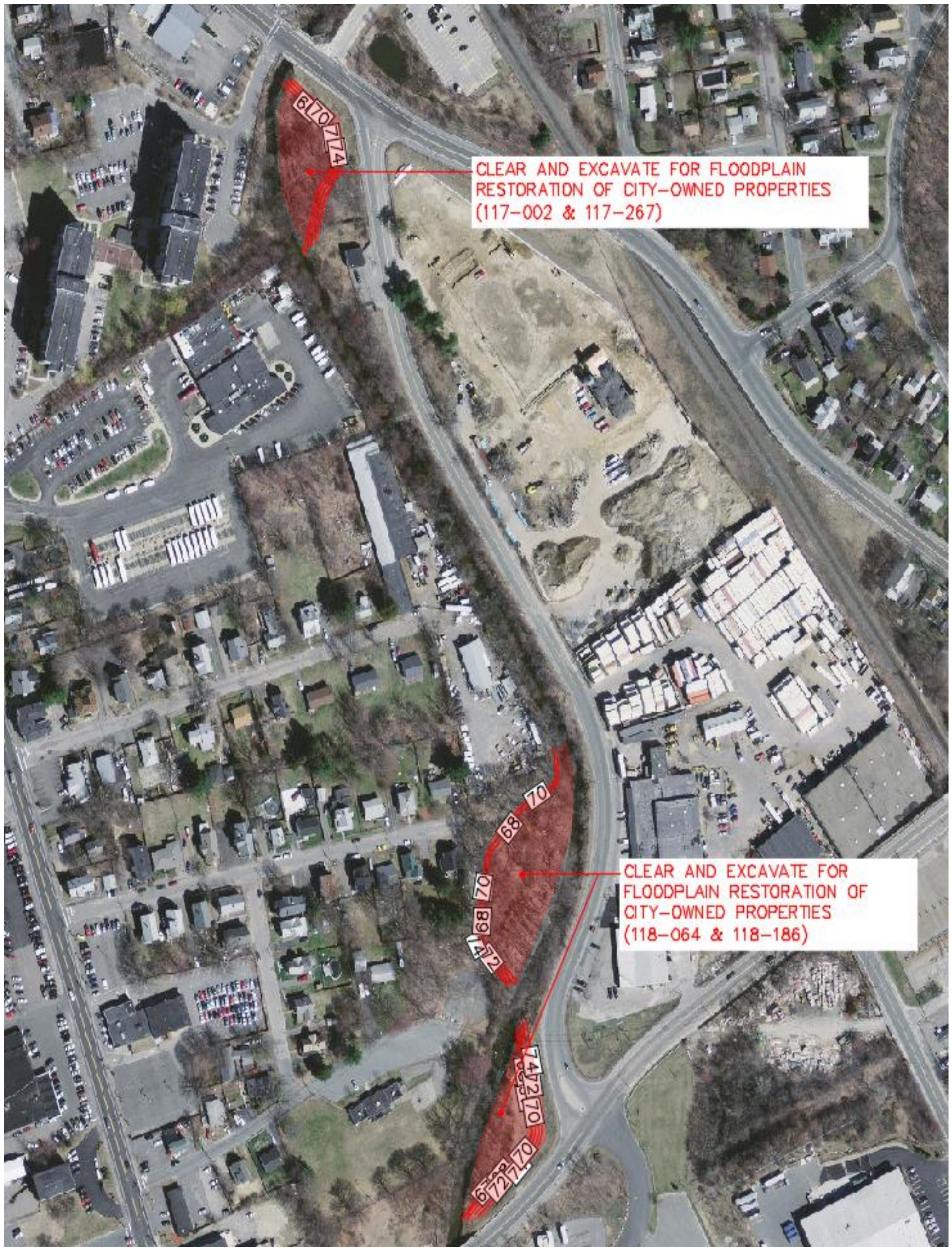


Figure 8-25. Potential Floodplain Restoration Areas between Plain Street and Sargent's Way

There are three privately-owned properties immediately downstream of Sargent's Way that are located along a constricted section of the river channel (**Figure 8-26**). Given the close proximity of these privately-owned parcels to the City-owned parcels between Plain Street and Sargent's Way, the clearing and excavation of approximately 22,500 cubic yards of material between EL 66.0 and 72.0 feet (NAVD88) from these properties is also proposed as part of this alternative.

Since these areas are privately owned, a temporary construction easement to allow for the clearing and excavation of material from both properties would be required followed by the execution of permanent easements that would restrict future development/ construction. Alternatively, these areas could be purchased by the City.

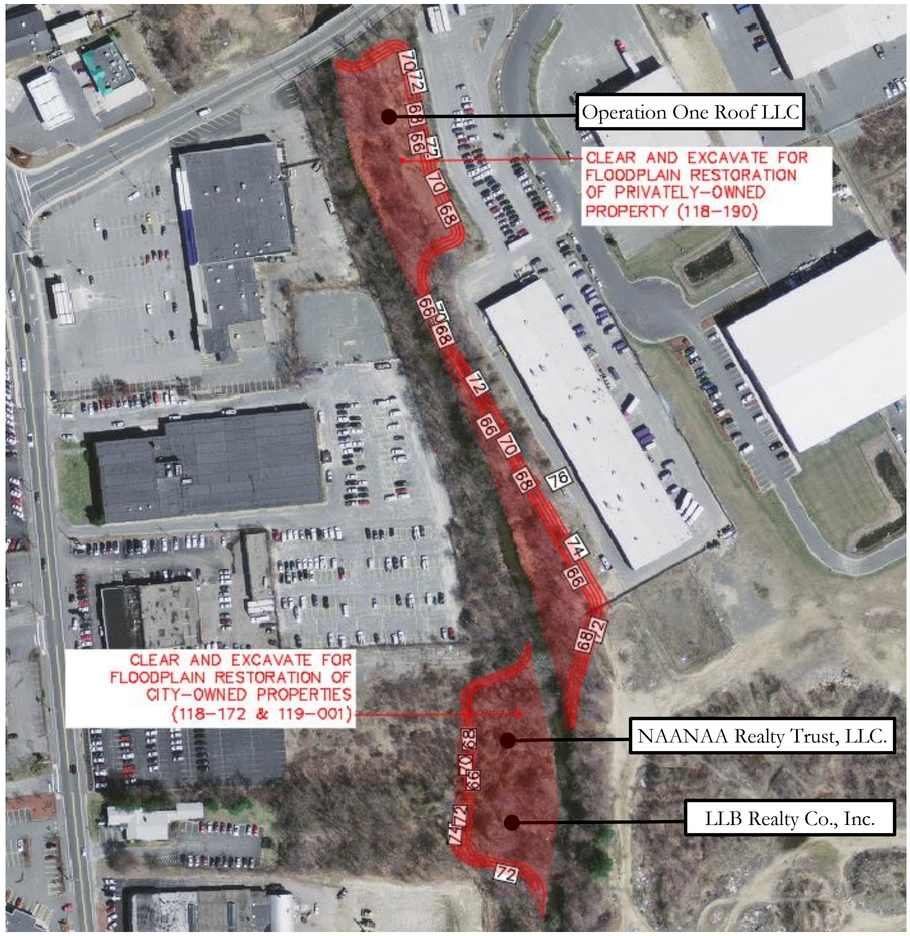


Figure 8-26. Potential Floodplain Restoration Areas Downstream of Sargent's Way

Based on the results of the HEC-RAS analysis, it appears that floodplain restoration for this alternative will result in the following flood reductions as reflected in **Table 8-10**. Values shaded in light blue indicate locations where flood reductions will exceed two inches.

Table 8-10. Undeveloped Parcel Alternative 2 (UP-2) Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Reduction	10-Year Avg. WSE Reduction	50-Year Avg. WSE Reduction	100-Year Avg. WSE Reduction	500-Year Avg. WSE Reduction
Elmwood Avenue to Prospect Street	0.0	0.0	0.0	0.0	0.0
Prospect Street to Pleasant Street	0.0	0.0	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	0.0	0.0	0.0	0.0	0.0
Moraine Street Conduit to Ash Street	0.0	0.0	0.0	0.0	0.0
Ash Street to Belmont Avenue	0.0	0.0	0.0	0.0	0.0
Belmont Avenue to Carleton Street	0.0	0.0	0.0	0.0	0.0
Carleton Street to No. Arlington Culvert	0.0	0.0	0.0	0.0	0.0
Belmont Street (123) to Warren Avenue	0.0	0.0	0.0	0.0	0.0
Warren Avenue to Allen Street	0.0	0.0	0.0	0.0	0.0
Allen Street to White Avenue	0.0	0.0	0.0	0.0	0.0
White Avenue to Railroad Bridge	0.0	0.0	0.0	0.0	0.0

Location in River System	2-Year Avg. WSE Reduction	10-Year Avg. WSE Reduction	50-Year Avg. WSE Reduction	100-Year Avg. WSE Reduction	500-Year Avg. WSE Reduction
Railroad Bridge to Otis Street	0.0	0.0	0.0	0.0	0.0
Otis Street to Grove Street	0.0	0.0	0.0	0.0	0.0
Grove Street to Pine Avenue	0.0	-0.1	0.0	-0.1	0.0
Pine Avenue to Perkins Avenue	-0.2	-0.2	-0.2	-0.2	-0.1
Perkins Avenue to Plain Street	-0.5	-0.5	-0.3	-0.4	-0.1
Plain Street to Sargent's Way	-0.6	-0.7	-0.6	-0.7	-0.6
Sargent's Way to WWTP/K-Mart Plaza	-0.1	-0.1	-0.1	-0.2	-0.1

Notes:
1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

As shown in the above table and **Figure 8-27** below, it appears that this alternative will have beneficial impacts throughout the lower end of the river system downstream of Pine Avenue. The most significant impacts are anticipated to occur between Plain Street and Sargent's Way. However, there are locations upstream of Plain Street in the vicinity of Pine Avenue and Perkins Avenue where notable reductions (of greater than 2 inches) would also be anticipated during all storm events analyzed.

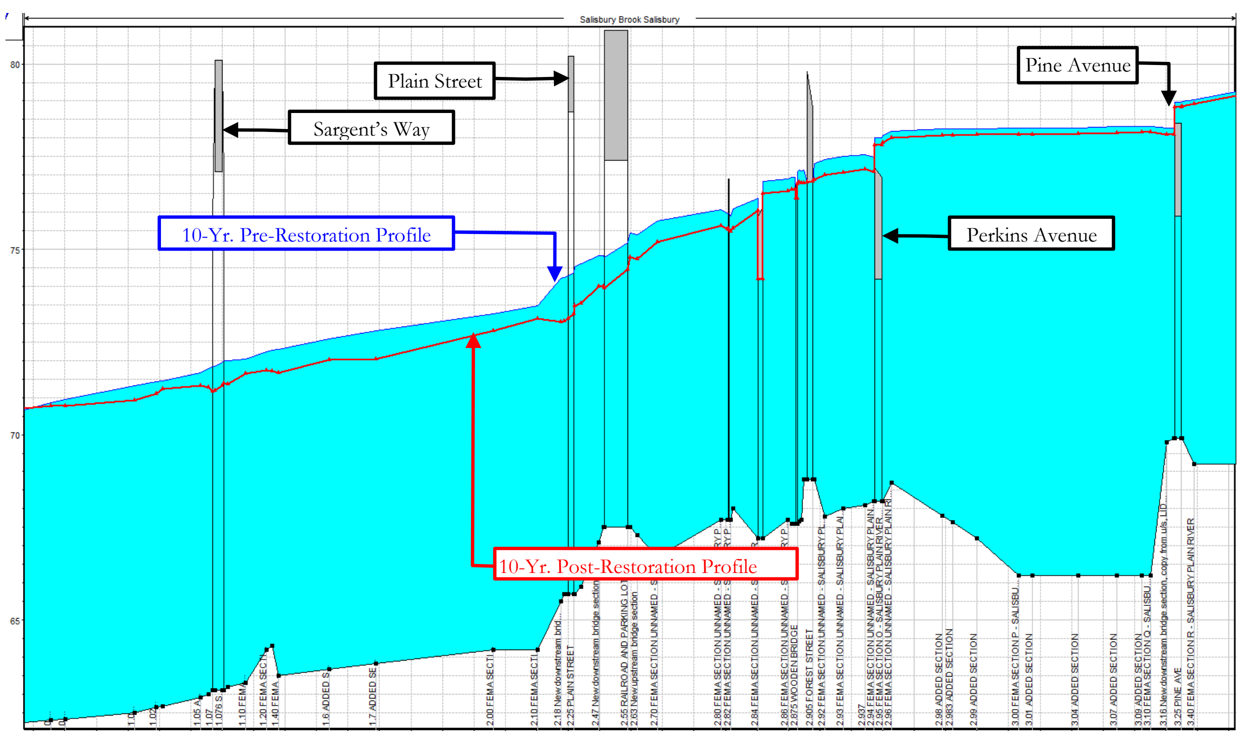


Figure 8-27. UP-2 Pre- Versus Post-Improvement 50-Year Water Surface Elevation Profile Comparison (from Pine Avenue to Sargent's Way)

8.3.3 Alternative UP-3 Summary & Hydraulic Analysis Results

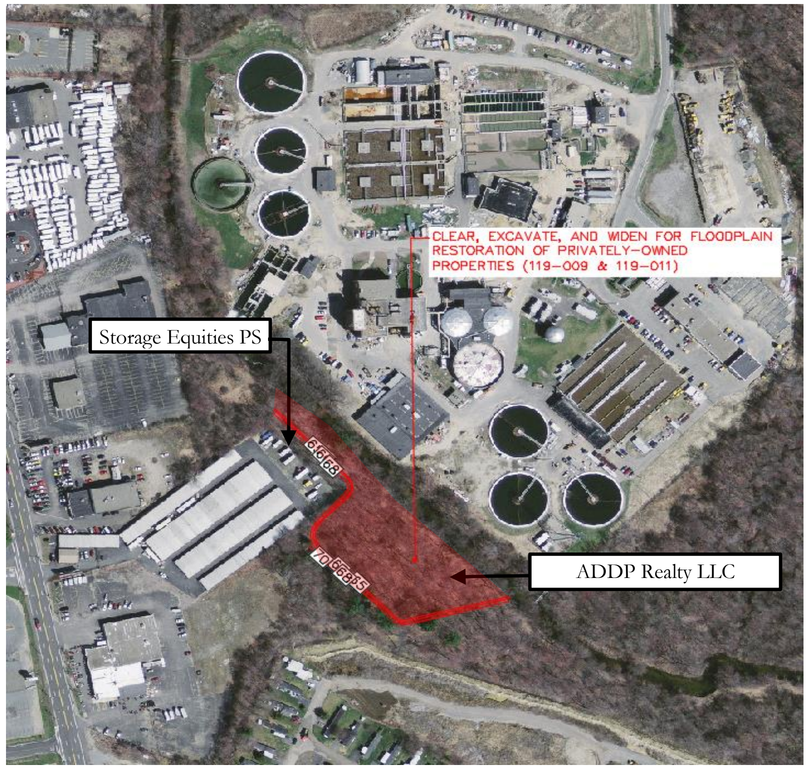


Figure 8-28. Potential Floodplain Restoration Areas between Plain Street and Sargent's Way

This alternative involves widening the river floodplain in the vicinity of the Brockton Wastewater Treatment Plant. Increasing the width of the floodplain within the undeveloped section of the Storage Equities PS property (at 2030 Main Street), which is identified as Parcel 119-009 and the undeveloped portion of the property located just south, owned by ADDP Realty LLC and identified as Parcel 119-011, would provide relief to flood flows upstream of this location and would result in flood level reductions during the storm events analyzed. Because work would be required on privately-owned properties, this alternative would require a temporary construction easement to allow for the clearing and excavation of material from both properties followed by the execution of permanent easements that would restrict future development/ construction. Alternatively, these areas could be purchased by the City. Approximately 2.0 acres would be cleared in addition to the removal of approximately 11,000 cubic yards of material from the floodplain between EL 65.0 and 70.0 (NAVD88) as shown in **Figure 8-28**.

Based on the results of our analysis, it appears that widening the channel and providing floodplain restoration across from the WWTP will have the following impacts for the analyzed flood events. Values shaded in light blue indicate locations where flood reductions will exceed two inches.

The localized benefits of greater than 2 inches for all flood events analyzed are relatively good in comparison to the amount of excavation required (11,000 cubic yards) compared to some of the other alternatives. Since the partial flooding of the K-Mart Plaza occurs even during the smaller, more frequent flood events such as the 2- and 10-year storm events, this restoration alternative will assist in reducing the extent of flooding within the plaza during all flood events analyzed. **Figure 8-29** shown below illustrates the reduction in 2-year flood elevations for this alternative. To further maximize flood benefits provided by increasing the wdith of the river's floodplain within this location, additional property buy-outs along this section of the river reach will be explored as described further in Section 1.4.

Table 8-11. Undeveloped Parcel Alternative 3 (UP-3) Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Reduction	10-Year Avg. WSE Reduction	50-Year Avg. WSE Reduction	100-Year Avg. WSE Reduction	500-Year Avg. WSE Reduction
Elmwood Avenue to Prospect Street	0.0	0.0	0.0	0.0	0.0
Prospect Street to Pleasant Street	0.0	0.0	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	0.0	0.0	0.0	0.0	0.0
Moraine Street Conduit to Ash Street	0.0	0.0	0.0	0.0	0.0
Ash Street to Belmont Avenue	0.0	0.0	0.0	0.0	0.0
Belmont Avenue to Carleton Street	0.0	0.0	0.0	0.0	0.0
Carleton Street to No. Arlington Culvert	0.0	0.0	0.0	0.0	0.0
Belmont Street (123) to Warren Avenue	0.0	0.0	0.0	0.0	0.0
Warren Avenue to Allen Street	0.0	0.0	0.0	0.0	0.0
Allen Street to White Avenue	0.0	0.0	0.0	0.0	0.0
White Avenue to Railroad Bridge	0.0	0.0	0.0	0.0	0.0
Railroad Bridge to Otis Street	0.0	0.0	0.0	0.0	0.0
Otis Street to Grove Street	0.0	0.0	0.0	0.0	0.0
Grove Street to Pine Avenue	0.0	0.0	0.0	0.0	0.0
Pine Avenue to Perkins Avenue	0.0	0.0	0.0	0.0	0.0
Perkins Avenue to Plain Street	0.0	0.0	0.0	0.0	0.0
Plain Street to Sargent's Way	-0.1	0.0	0.0	0.0	0.0
Sargent's Way to WWTP/K-Mart Plaza	-0.2	-0.2	-0.2	-0.2	-0.2

Notes:

1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

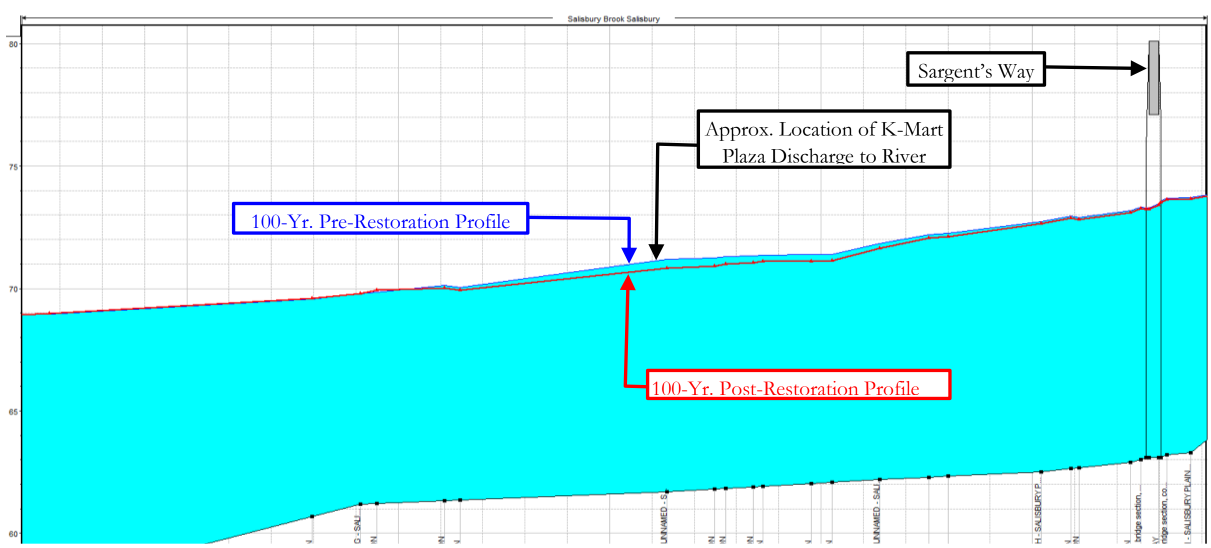


Figure 8-29. UP-3 Pre- Versus Post-Improvement 100-Year Water Surface Elevation Profile Comparison (Downstream of Sargent's Way near K-Mart Outlet to River)

8.3.4 Undeveloped Property Alternative Cost/Benefit Analysis Summary

The following qualitative cost/benefit evaluation table has been provided to serve as a preliminary decision-making tool for evaluating the overall benefits and costs associated with each undeveloped property flood reduction alternative. The table has been populated with order of magnitude costs, flood reduction benefit summaries (for each flood event analyzed), and qualitative benefit-to-cost ratings for each alternative considered (in respect to the other alternatives). The benefit-to-cost rating is based on a scale of "low" to "high," with "high" being the most advantageous and "low" being the most disadvantageous in terms of flood reductions with respect to costs. The ratings also consider the amount of flood elevation reduction that occurs in locations that have been identified as areas of frequent or known residential and/or commercial flooding and where roadway closures have been reported due to previously reported bridge/roadway inundation.

Table 8-12. Undeveloped Parcel Alternatives Flood Reduction Summary and Qualitative Benefit-to-Cost Score

Conceptual Alternative	Average Flood Reduction Benefits	Opinion of Cost	B/C Score
UP Alt.1 (UP-1)	**2-Year Flood:** • Reduces flood elevations between White Avenue Bridge to Railroad Bridge by 2" or less **10-Year Flood:** • Reduces flood elevations between White Avenue and Montello Street by 3" or less • Reduces flood elevations between Montello Street and Railroad Bridge by 3" or less **50-Year Flood:** • Reduces flood elevations between Allen Street and White Avenue by 4" to 7" • *Eliminates Overtopping of White Avenue Bridge* • Reduces flood elevations between White Avenue and Montello Street by 6" to 8" • Reduces flood elevations between Montello Street and Railroad Bridge by 2" to 7" **100-Year:** • Reduces flood elevations between Allen Street and White Avenue by 1" to 2" • Reduces flood elevations between White Avenue and Montello Street by 2" to 3" • Reduces flood elevations between Montello Street and Railroad Bridge by 1" to 5" **500-Year:** • Reduces flood elevations between Allen Street and White Avenue by 1" or less • Reduces flood elevations between White Avenue and Montello Street by 1" to 4" • Reduces flood elevations between Montello Street and Railroad Bridge by 1" to 10"	$1.7M-$3.3M	Low
UP Alt. 2 (UP-2)	**2-Year Flood:** • Reduces flood elevations between Pine Avenue and Perkins Avenue by 2" to 3" • Reduces flood elevations between Perkins Avenue and Plain Street by 4" to 13" • Reduces flood elevations between Plain Street and Sargent's Way by 4" to 13" • Reduces flood elevations between Sargent's Way to City Boundary by 1" to 6" **10- Year Flood:** • Reduces flood elevations between Pine Avenue and Perkins Avenue by 2" to 3" • Reduces flood elevations between Perkins Avenue and Plain Street by 4" to 13" • Reduces flood elevations between Plain Street and Sargent's Way by 5" to 13"	$2.5M-$4.8M	Medium

Conceptual Alternative	Average Flood Reduction Benefits	Opinion of Cost	B/C Score
	• Reduces flood elevations between Sargent's Way to City Boundary by 1" to 8" **50-Year Flood:** • Reduces flood elevations between Pine Avenue and Perkins Avenue by 1" to 2" • Reduces flood elevations between Perkins Avenue and Plain Street by 2" to 7" • Reduces flood elevations between Plain Street and Sargent's Way by 5" to 10" • Reduces flood elevations between Sargent's Way to City Boundary by 1" to 9" **100-Year Flood:** • Reduces flood elevations between Pine Avenue and Perkins Avenue by 1" to 2" • Reduces flood elevations between Perkins Avenue and Plain Street by 2" to 8" • Reduces flood elevations between Plain Street and Sargent's Way by 5" to 10" • Reduces flood elevations between Sargent's Way to City Boundary by 1" to 10" **500-Year Flood:** • Reduces flood elevations between Pine Avenue and Perkins Avenue by 1" to 2" • Reduces flood elevations between Perkins Avenue and Plain Street by 1" to 3" • Reduces flood elevations between Plain Street and Sargent's Way by 5" to 9" • Reduces flood elevations between Sargent's Way to City Boundary by 1" to 10"		
UP Alt. 3 (UP-3)	**2-Year Flood:** • Reduces flood elevations between Sargent's Way to WWTP by 1" to 3" • Reduces flood elevations at K-Mart Plaza Discharge to River by 2" to 3" **10- Year Flood:** • Reduces flood elevations between Sargent's Way to WWTP by 1" to 4" • Reduces flood elevations at K-Mart Plaza Discharge to River by 3" to 4" **50-Year Flood:** • Reduces flood elevations between Sargent's Way to WWTP by 1" to 4" • Reduces flood elevations at K-Mart Plaza Discharge to River by 3" to 4" **100-Year Flood:** • Reduces flood elevations between Sargent's Way to WWTP by 1" to 4" • Reduces flood elevations at K-Mart Plaza Discharge to River by 3" to 4" **500-Year Flood:** • Reduces flood elevations between Sargent's Way to WWTP by 1" to 5" • Reduces flood elevations at K-Mart Plaza Discharge to River by 4" to 5"	$1.0-$2.0M	Low

Full-size water surface profiles, hydraulic analysis summary data, and more detailed breakdowns of order of magnitude opinions of cost for each of the undeveloped parcel floodplain restoration alternatives are provided in **Appendix D**.

In reviewing these undeveloped parcel floodplain restoration alternatives, it appears that UP Alternative 2 (UP-2) would provide the most value of the three alternatives considered under this section in terms of the amount and extent of flood reductions that would be expected. Flood reductions of greater than 2 inches would be realized throughout a 1.3-mile section of the river from Pine Avenue to a point approximately 900 feet downstream of Sargent's Way for all storm events.
While UP Alternative 3 (UP-3) showed reductions of between 2 to 5 inches for all events analyzed (i.e. in the location where the discharge culvert from the K-Mart Plaza enters the River), such reductions

were localized to a 0.4-mile stretch of the river between Sargent's Way and the WWTP. While this alternative may help with flooding at the K-Mart Plaza, these reductions would not result in the removal of any structures from the floodplain limits associated with each flooding event.

Similarly, flood reductions for UP Alternative 1 (UP-1) were limited to a 0.3-mile stretch of the River primarily between Allen Street and the Railroad Bridge crossing just downstream (or east) of Montello Street. While these reductions would eliminate the overtopping of the White Avenue Bridge crossing during the 50-year flood, it does not appear that there would be any other major benefits in this area since much of the flooding that occurs in this area occurs when the river overtops its banks during the 100-year and 500-year floods.

8.4 Floodplain Restoration of Developed Parcels

These alternatives analyze the partial or full buyout and restoration of developed parcels that exist in or adjacent to areas of critical flooding throughout the river system. This includes locations where repetitive loss properties and/or roadway flooding has been reported and existing uses could be feasibly relocated to a more resilient location. Because property buyouts are more complicated (e.g., legally, and socially) than using vacant land owned by the City, the benefits will need to be relatively high to justify the cost. Three options for partial or full buyout and/or restoration of developed property were considered:

- Full purchase/buyout of Parcel 043-001, which is located at the corner of Prospect Street and Pleasant Street, and the permanent conversion of the undeveloped portion of Parcel 043-002 for land dedicated to floodplain restoration.
- Full purchase/buyout of the Belmont Avenue church property (Parcel 048-130), which is located at 144 Belmont Avenue, and conversion of this area to land dedicated to floodplain restoration.
- Partial purchase of the undeveloped portions of 14 commercial parcels located along the River between Sargent's Way and the City's boundary with West Bridgewater in order to increase the River's floodplain width for conveyance and its storage by approximately 30,200 cubic yards.

8.4.1 Alternative DP-1 Summary & Hydraulic Analysis Results

This alternative was proposed to provide additional flood storage in the upper (upstream) portion of Salisbury Brook with the intent of reducing flows discharged to downstream portions of the Brook including the frequently flooded Belmont Avenue area. Consequently, this alternative proposes the removal of approximately 10,400 cubic yards of material from the floodplain along the left and right sides of Salisbury Brook between Prospect and Pleasant Streets.

This area consists of two privately-owned properties, Parcel 043-001 located on river right and Parcel 043-002 located on river left. While Parcel 043-002 consists of undeveloped area, Parcel 043-001 contains a vacant/dilapidated building structure (formerly Beacon Street Sportswear) and associated pavement area throughout much of the property. As a result, this property would need to be purchased by the City and the structure and its associated pavement would need to be demolished and removed prior to the excavation of approximately 6,500 cubic yards of material from this property between El. 126.0 and El. 132.0 feet (NAVD88). The assessed value of this property is listed as $320,000.

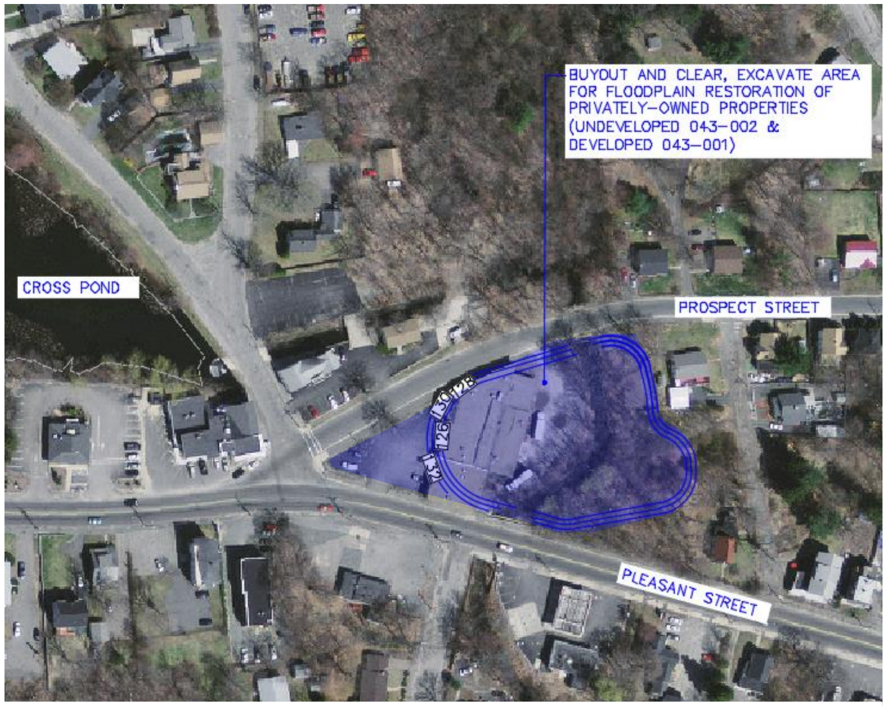


Figure 8-30. Potential Floodplain Restoration Area of Parcels at the Prospect Street /Pleasant Street Intersection (Upstream of Frequently Flooded Belmont Avenue Area)

The parcel on the opposite side of the Brook, Parcel 043-001, consists of undeveloped, wooded area. The partial clearing (0.40 acres of 0.91 acres) and excavation of this area would result in the removal of approximately 3,900 cubic yards from this location. Since this property is also privately owned, this property would need to be purchased by the City. The assessed value of this property is listed as $10,000. Alternatively, a temporary construction easement could be executed with the property owner to allow for the partial clearing and excavation of material from this property followed by the execution of a permanent easement that would restrict future development/ construction.

Based on the results of our analysis, it appears that widening the channel and providing floodplain restoration within this stretch of the river will have the following impacts for the analyzed flood events. Values shaded in light blue indicate locations where flood reductions will exceed two inches.

Table 8-13. Developed Parcel Alternative 1 (DP-1) Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Reduction	10-Year Avg. WSE Reduction	50-Year Avg. WSE Reduction	100-Year Avg. WSE Reduction	500-Year Avg. WSE Reduction
Elmwood Avenue to Prospect Street	-0.1	-0.1	0.0	-0.1	0.0
Prospect Street to Pleasant Street	-0.1	-0.1	0.0	-0.1	0.0
Pleasant Street to Moraine Street Conduit	0.0	-0.1	0.0	-0.2	0.0
Moraine Street Conduit to Ash Street	0.0	-0.1	-0.1	-0.5	0.0
Ash Street to Belmont Avenue	0.0	0.0	0.0	0.0	0.0
Belmont Avenue to Carleton Street	-0.1	0.0	0.0	-0.1	0.0
Carleton Street to No. Arlington Culvert	-0.1	-0.1	-0.1	0.0	0.0
Belmont Street (123) to Warren Avenue	-0.1	-0.1	0.0	-0.1	0.0
Warren Avenue to Allen Street	-0.1	-0.1	0.0	-0.1	0.0
Allen Street to White Avenue	0.0	0.0	-0.2	-0.2	0.0
White Avenue to Railroad Bridge	-0.1	-0.1	-0.2	-0.2	0.0
Railroad Bridge to Otis Street	-0.1	-0.1	-0.1	-0.2	0.0

Location in River System	2-Year Avg. WSE Reduction	10-Year Avg. WSE Reduction	50-Year Avg. WSE Reduction	100-Year Avg. WSE Reduction	500-Year Avg. WSE Reduction
Otis Street to Grove Street	0.0	0.0	0.0	-0.1	0.0
Grove Street to Pine Avenue	0.0	0.0	0.0	-0.1	0.0
Pine Avenue to Perkins Avenue	0.0	0.0	0.0	-0.1	0.0
Perkins Avenue to Plain Street	0.0	0.0	0.0	-0.1	0.0
Plain Street to Sargent's Way	0.0	0.0	0.0	-0.1	0.0
Sargent's Way to WWTP/K-Mart Plaza	0.0	0.0	0.0	0.0	0.0

Notes:

1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

Localized improvements during the 100-year from Pleasant Street to Ash Street, are the primary benefit of this alternative; other flood reduction benefits were very limited.

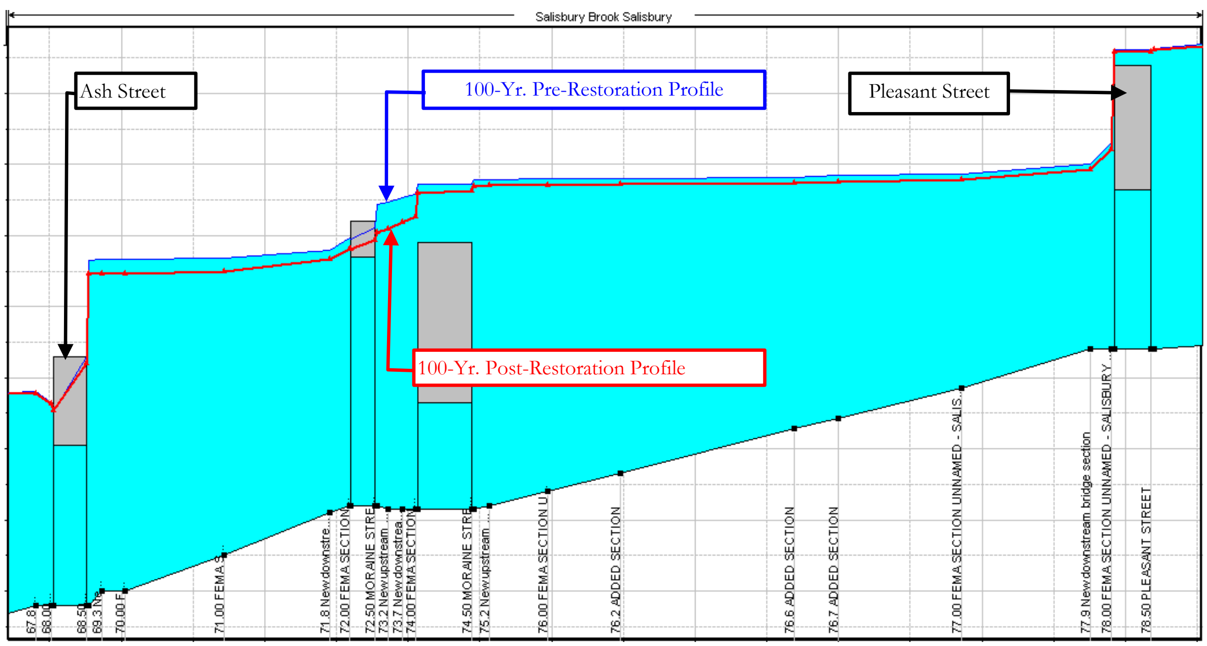


Figure 8-31. DP-1 Pre- Versus Post-Improvement 100-Year Water Surface Elevation Profile Comparison (Between Pleasant Street and Ash Street)

8.4.2 Alternative DP-2 Summary & Hydraulic Analysis Results

Figure 8-32. Potential Floodplain Restoration Area of Parcel 048-130 within Frequently Flooded Belmont Avenue Area

This alternative was also proposed with the intent of reducing flooding within the frequently flooded Belmont Avenue area. Unlike Alternative DP-1, however, this alternative proposes an increase of floodplain storage within the Belmont Avenue area as opposed to upstream of it. Salisbury Brook between Belmont Avenue and Carleton Street has a gently sloping channel bottom and relatively flat hydraulic slope. To determine if providing added flood storage would have substantial floodplain reductions in this area, the removal of approximately 8,200 cubic yards of material from the Brook's floodplain between El. 114.0 and El. 118.0 feet (NAVD88) was proposed at 144 Belmont Avenue (or Parcel 048-130). This parcel was selected given its relatively large size and location immediately along the river channel. The parcel is a1.6-acre privately-owned property that contains a church structure and a large impervious parking area to the north. As a result, this property would need to be purchased by the City and the structure and its associated pavement would need to be demolished and removed prior to the excavation of material from floodplain. The assessed value of this property is listed as $375,000.

Based on the results of our analysis as reflected in the following table, it appears that providing floodplain restoration within this stretch of the river will have insignificant floodplain reductions throughout the Brook and Salisbury Plain River.

Table 8-14. Developed Parcel Alternative 2 (DP-2) Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Reduction	10-Year Avg. WSE Reduction	50-Year Avg. WSE Reduction	100-Year Avg. WSE Reduction	500-Year Avg. WSE Reduction
Elmwood Avenue to Prospect Street	0.0	0.0	0.0	0.0	0.0
Prospect Street to Pleasant Street	0.0	0.0	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	0.0	0.0	0.0	-0.1	0.0
Moraine Street Conduit to Ash Street	0.0	0.0	0.0	-0.1	0.0
Ash Street to Belmont Avenue	-0.1	0.0	0.0	0.0	0.0
Belmont Avenue to Carleton Street	-0.1	-0.1	-0.1	-0.1	0.0
Carleton Street to No. Arlington Culvert	0.0	0.0	0.0	0.0	0.0
Belmont Street (123) to Warren Avenue	0.0	-0.1	0.0	-0.1	0.0

Location in River System	2-Year Avg. WSE Reduction	10-Year Avg. WSE Reduction	50-Year Avg. WSE Reduction	100-Year Avg. WSE Reduction	500-Year Avg. WSE Reduction
Warren Avenue to Allen Street	0.0	-0.1	0.0	0.0	0.0
Allen Street to White Avenue	0.0	-0.1	-0.1	-0.1	0.0
White Avenue to Railroad Bridge	0.0	-0.1	-0.1	-0.1	0.0
Railroad Bridge to Otis Street	-0.0	-0.1	-0.1	-0.1	0.0
Otis Street to Grove Street	0.0	0.0	0.0	-0.1	0.0
Grove Street to Pine Avenue	0.0	0.0	0.0	0.0	0.0
Pine Avenue to Perkins Avenue	0.0	0.0	0.0	0.0	0.0
Perkins Avenue to Plain Street	0.0	0.0	0.0	0.0	0.0
Plain Street to Sargent's Way	0.0	0.0	0.0	0.0	0.0
Sargent's Way to WWTP/K-Mart Plaza	0.0	0.0	0.0	0.0	0.0

Notes:

1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

8.4.3 Alternative DP-3 Summary & Hydraulic Analysis Results

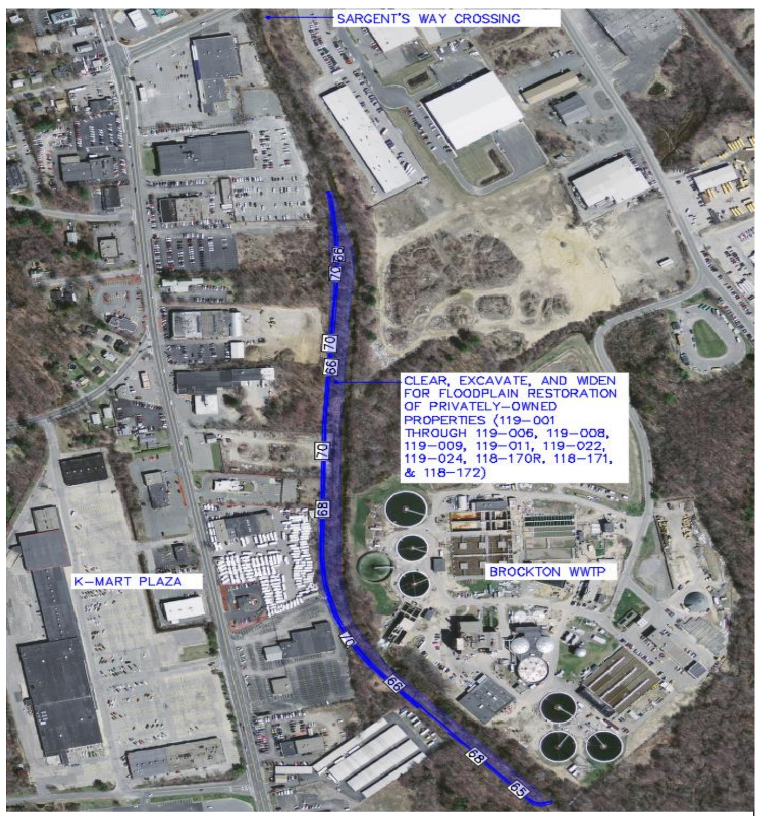


Figure 8-33. Potential Restoration Areas between Plain Street and Sargent's Way

This alternative proposes the removal of approximately 30,200 cubic yards of material from the floodplain along the right side of an approximately 3,000-foot stretch of the river between Sargent's Way and the City's boundary with West Bridgewater. The intent of this alternative is to lower flood elevations within the section of the Salisbury Plain River downstream of Sargent's Way where the discharge channel from the K-Mart Plaza (Plaza) is located. Lower flood elevations in this section of the River could assist in reducing flood risk to commercial properties located along the River as well as improve flooding within the Plaza since river levels during flood events impact the ability of the Plaza's drainage system to effectively convey flow away from the Plaza and to the River.

This area consists of approximately

14 commercial properties that are privately owned. Although the majority of these properties are developed, the intent of this alternative is to excavate material within an approximate 75-foot swath of land immediately adjoining the right side of the river channel that does not include any impervious surfaces or structures. This will increase floodplain storage in this area by approximately 30,200 cubic yards between El. 65.0 and El. 70.0 feet (NAVD88) and reduce any geometric constrictions that may exist within this stretch of the river due to previous development.

Since these areas are within privately owned parcels, a temporary construction easement to allow for the clearing and excavation of material from all properties would be required followed by the execution of permanent easements that would restrict future development/construction. Alternatively, these areas could be purchased by the City. Based on the City's latest assessor data, the typical land value for undeveloped portions of properties in this area is approximately $35k/acre and approximately $250k/acre for developed portions of property.

Based on the results of our analysis, it appears that widening the channel and providing floodplain restoration within this stretch of the river will have the following impacts for the analyzed flood events. Values shaded in light blue indicate locations where flood reductions will exceed two inches.

Table 8-15. Developed Parcel Alternative 3 (DP-3) Hydraulic Analysis Modeling Results

Location in River System	2-Year Avg. WSE Reduction	10-Year Avg. WSE Reduction	50-Year Avg. WSE Reduction	100-Year Avg. WSE Reduction	500-Year Avg. WSE Reduction
Elmwood Avenue to Prospect Street	0.0	0.0	0.0	0.0	0.0
Prospect Street to Pleasant Street	0.0	0.0	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	0.0	0.0	0.0	0.0	0.0
Moraine Street Conduit to Ash Street	0.0	0.0	0.0	0.0	0.0
Ash Street to Belmont Avenue	0.0	0.0	0.0	0.0	0.0
Belmont Avenue to Carleton Street	0.0	0.0	0.0	0.0	0.0
Carleton Street to No. Arlington Culvert	0.0	0.0	0.0	0.0	0.0
Belmont Street (123) to Warren Avenue	0.0	0.0	0.0	0.0	0.0
Warren Avenue to Allen Street	0.0	0.0	0.0	0.0	0.0
Allen Street to White Avenue	0.0	0.0	0.0	0.0	0.0
White Avenue to Railroad Bridge	0.0	0.0	0.0	0.0	0.0
Railroad Bridge to Otis Street	0.0	0.0	0.0	0.0	0.0
Otis Street to Grove Street	0.0	0.0	0.0	0.0	0.0
Grove Street to Pine Avenue	0.0	0.0	0.0	0.0	0.0
Pine Avenue to Perkins Avenue	0.0	0.0	0.0	0.0	0.0
Perkins Avenue to Plain Street	0.0	0.0	0.0	0.0	0.0
Plain Street to Sargent's Way	-0.2	-0.2	-0.2	-0.2	-0.2
Sargent's Way to WWTP/K-Mart Plaza	-0.3	-0.3	-0.3	-0.4	-0.4

Notes:
1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

As shown in the table above, this alternative will result in localized floodplain reductions between Plain Street and the City's boundary with West Bridgewater. Average flood elevation reductions would range between 0.2 to 0.3 feet (or 2 to 4 inches) for the 2-, 10-, and 50-year flood events and between 0.2 to 0.4 feet (or 2 to 5 inches) for the 100-year and 500-year flood events. For all events analyzed, the actual reduction in flood elevations where the discharge from the K-Mart Plaza enters the river will range between 4 to 5 inches. **Figure 8-34** shown below illustrates the reduction in 100-year flood elevations for this alternative.

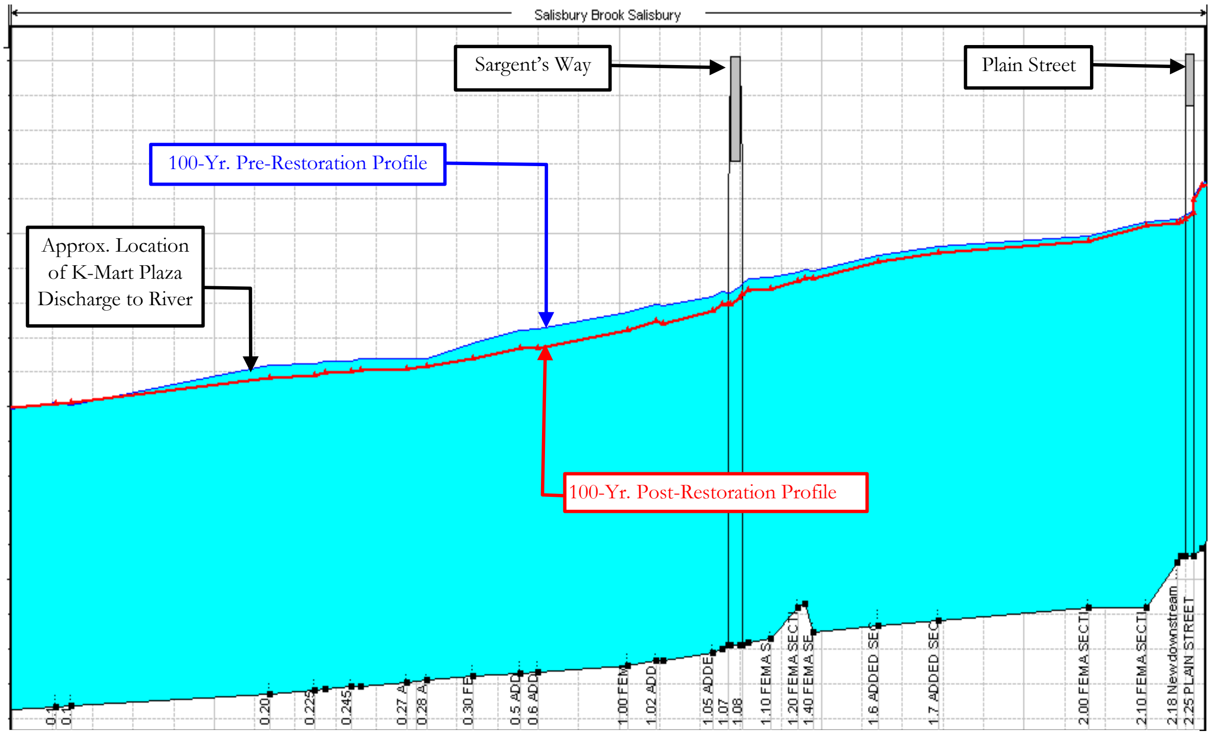


Figure 8-34. DP-3 Pre- Versus Post-Improvement 100-Year Water Surface Elevation Profile Comparison (Downstream of Sargent's Way near K-Mart Outlet to River)

8.4.4 Developed Property Alternative Cost/Benefit Analysis Summary

The following qualitative cost/benefit evaluation table has been provided to serve as a preliminary decision-making tool for evaluating the overall benefits and costs associated with each developed property flood reduction alternative. The table has been populated with order of magnitude costs, flood reduction benefit summaries (for each flood event analyzed), and qualitative benefit-to-cost ratings for each alternative considered (in respect to the other alternatives). The benefit-to-cost rating is based on a scale of "low" to "high," with "high" being the most advantageous and "low" being the most disadvantageous in terms of flood reductions with respect to costs. The ratings also consider the amount of flood elevation reduction that occurs in locations that have been identified as areas of frequent or known residential and/or commercial flooding and where roadway closures have been reported due to previously reported bridge/roadway inundation.

Table 8-16. Developed Parcel Alternatives Flood Reduction Summary and Qualitative Benefit-to-Cost Score

Conceptual Alternative	Average Flood Reduction Benefits	Opinion of Cost	B/C Score
DP Alt.1 (DP-1)	**2-, 10-, and 50-Year Flood**: Insignificant flood reductions **100-Year Flood:** • Reduces flood elevations between Pleasant Street and Moraine Conduit by2" to 3" • Reduces flood elevations between Moraine Conduit and Ash Street by 3" to 9" **500-Year Flood:** Insignificant flood reductions	$1.4M-$2.8M	Low
DP Alt. 2 (DP-2)	**2-Year Flood:** • Reduces flood elevations between Belmont Avenue and Spring Street by 1" to 3" • Reduces flood elevations between Spring Street and Carleton Street by 1" to 4" **10- Year Flood:** • Reduces flood elevations between Belmont Avenue and Spring Street by 1" to2" • Reduces flood elevations between Spring Street and Carleton Street by 1" to 2" **50-Year Flood:** • Reduces flood elevations between Belmont Avenue and Spring Street by up to 1" • Reduces flood elevations between Spring Street and Carleton Street by 1" to 2" **100-Year Flood:** • Reduces flood elevations between Belmont Avenue and Spring Street by up to 1" • Reduces flood elevations between Spring Street and Carleton Street by 1" to 2" **500-Year Flood:** • Reduces flood elevations between Belmont Avenue and Spring Street by up to 1" • Reduces flood elevations between Spring Street and Carleton Street by up to 1"	$1.7M-$2.3M	Low
DP Alt. 3 (DP-3)	**2-Year, 10-Year, and 50-Year Floods:** • Reduces flood elevations between Plain Street and Sargent's Way by 1" to4" • Reduces flood elevations between Sargent's Way to K-Mart Plaza Discharge by 4" to 6" **100-Year and 500-Year Floods:** • Reduces flood elevations between Plain Street and Sargent's Way by 1" to4" • Reduces flood elevations between Sargent's Way to K-Mart Plaza Discharge by 4" to 7"	$2.1-$4.1M	Low

Full-size water surface profiles, hydraulic analysis summary data, and more detailed breakdowns of order of magnitude opinions of cost for each of the developed parcel floodplain restoration alternatives are provided in **Appendix D**.

In reviewing these undeveloped parcel floodplain restoration alternatives, it appears that none of these alternatives have high benefit to cost ratios as stand-alone alternatives.

8.5 Preferred Composite Alternative

The hydraulic results and relative costs and benefits associated with each of the analyzed flood reduction alternatives were reviewed comprehensively to develop four composite flood reduction alternatives that would potentially provide the most flood reduction benefits in frequently flooded areas throughout the

City with consideration to costs. These four alternatives were then evaluated further in order to ultimately decide upon the recommended preferred composite alternative.

In developing the four composite alternatives, the following key observations were made based on our evaluation of all flood reduction alternatives:

- Proposing flood reduction measures at Ellis Brett Pond will have benefits throughout both Salisbury Brook and Salisbury Plain River. For example, installing a gate at Ellis Brett Pond (EB-2) with no other improvements will have the highest benefit to cost ratio of all the alternatives analyzed. It will result in average flood reductions of 0.65 feet and 0.28 feet throughout Salisbury Brook and Salisbury Plain River, respectively, for the 2-year flood event and 0.42 feet and 0.10 feet, respectively, for the 10-year flood event. This will result in the elimination of the overtopping of the Belmont Avenue Bridge Crossing during the 2-year flood and the Prospect Street and Spring Street Bridge Crossings for the 10-year flood. However, there will only be an average reduction of 0.08 feet during the 50-year flood.
- While increasing the amount of storage provided by Ellis Brett Pond (EB-1) as a stand-alone alternative will have a low benefit to cost ratio, it will provide more significant reductions for the 50-year flood throughout Salisbury Brook when compared to the results from simply adding a gate. And if combined with the installation of a gate (EB-3), there will be a relatively substantial reduction in flood levels throughout several reported frequently flooded areas throughout the City. For example, combining added storage with the installation of a gate will result in average flood reductions of 0.69 feet and 0.38 feet throughout Salisbury Brook and Salisbury Plain River, respectively, for the 2-year flood event and 0.45 feet and 0.21 feet, respectively, for the 10-year flood event. Additionally, there will be an average reduction in flood levels of 0.41 feet throughout Salisbury Brook for the 50-year flood event. This will not only result in the elimination of the overtopping of the Belmont Avenue Bridge Crossing during the 2-year flood and the Prospect Street and Spring Street Bridge Crossings for the 10-year flood, but also the elimination of the overtopping of the White Street Bridge Crossing during the 50-year flood.
- Proposing flood reductions measures at Cross Pond (CP-1 through CP-3) will have minimal impacts on downstream flood elevations. The amount of storage provided by Cross Pond does not appear to be substantial enough in respect to its inflow volume.
- In reviewing the results of the undeveloped parcel flood reduction options, the only options that seemed to have more than localized flood reductions was the proposed increase in flood storage at three undeveloped (City-owned) properties between Plain Street and Sargent's Way and three privately-owned properties immediately downstream of Sargent's Way (UP-2). The increase of flood storage between Plain Street and Sargent's Way will result in flood reductions as far upstream as Pine Avenue while the increase in flood storage just downstream of Sargent's Way will almost double the amount of flood reductions that will be experienced between Plain Street and Sargent's Way for the 2- through 500-year flood events.
- Constrictions in floodplain geometry were observed in the vicinity of the Brockton Wastewater Treatment Plant just downstream of where the culvert from the K-Mart Plaza discharges into the River. Although removing one of these constrictions (as proposed under Alternative UP-3) will only have localized flood reductions of between 0.27 feet to 0.43 feet for 2- through 500-year flood events for a relatively short stretch of the Salisbury Plain River downstream of Sargent's Way, such reductions will occur at the discharge location of the K-Mart Plaza outfall. As a result, this will help to improve the hydraulic capacity of this K-Mart culvert and

potentially help to reduce peak flood levels in the K-Mart Plaza (although it will not solve the flooding problem). Although Alternative UP-3 has a low benefit to cost ratio as a stand-alone alternative, it could be used as part of a combined alternative strategy in collectively lowering flood levels throughout the Salisbury Plain River.

- Proposing flood reductions measures as proposed under the three developed parcel alternatives, DP-1 through DP-3, as described under Section 1.4 will have minimal and localized impacts on downstream flood elevations. As a result, these options result in low benefit to cost ratios.

In consideration of these observations, four composite alternatives were further developed and analyzed. The costs of each were also compared to their flood reduction benefits. These composite alternatives included:

- Composite Alternative 1: This included the installation of a gate structure at Ellis Brett Pond (EB-2) and the restoration of the three undeveloped, City-owned parcels between Plain Street and Sargent's Way along with the undeveloped portions of three privately-owned properties immediately downstream of Sargent's Way (UP-2). Compared to EB-2 alone, this composite option adds 4-6 inches of extra flood elevation reduction from Pine Ave. to Sargent's Way for the 2-yr storm and adds significant additional benefit in this area for the 10- to 500-yr storms.
- Composite Alternative 2: This included the installation of a gate structure at Ellis Brett Pond (EB-2); the restoration of the three undeveloped, City-owned parcels between Plain Street and Sargent's Way along with the undeveloped portions of three privately-owned properties immediately downstream of Sargent's Way (UP-2); and the widening of the river's floodplain in the vicinity of the Brockton Wastewater Treatment Plant (UP-3). This option increases flood elevation reductions below Plain Street, which may positively impact the K-Mart Plaza, however the added benefits are likely not offset by the increased costs.
- Composite Alternative 3: This included the installation of a gate structure at Ellis Brett Pond as well as the increase in storage volume of Ellis Brett Pond via the excavation of approximately 42,600 cubic yards of material (collectively known as EB-3); and the restoration of the three undeveloped, City-owned parcels between Plain Street and Sargent's Way along with the undeveloped portions of three privately-owned properties immediately downstream of Sargent's Way (UP-2). Compared to EB-3 alone, this composite option adds 2.5-6 inches of additional flood elevation reduction from Pine Ave. to Sargent's Way for the 2-yr storm and adds significant additional benefit in this area for the 10-yr through 500-yr storm events.
- Composite Alternative 4: This included the installation of a gate structure at Ellis Brett Pond as well as the increase in storage volume of Ellis Brett Pond via the excavation of approximately 42,600 cubic yards of material (collectively known as EB-3); the restoration of the three undeveloped, City-owned parcels between Plain Street and Sargent's Way along with the undeveloped portions of three privately-owned properties immediately downstream of Sargent's Way (UP-2); and the widening of the river's floodplain in the vicinity of the Brockton Wastewater Treatment Plant (UP-3). As with composite alternative 2, there is potential added benefit to the K-Mart Plaza, but at significant additional cost.

Based on the results of our analyses as reflected in the following tables, it was concluded that Composite Alternatives 1 and 3 provide the greatest flood reductions in respect to their costs on an overall, full river length review and would be our recommended preferred alternatives.

Table 8-17. Composite Alternative 1 (EB-2 & UP-2)

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Elmwood Avenue to Prospect Street	-1.0	-0.7	0.0	0.0	0.0
Prospect Street to Pleasant Street	-1.1	-0.7	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	-1.1	-1.0	-0.1	0.0	0.0
Moraine Street Conduit to Ash Street	-0.8	-0.7	-0.3	-0.1	-0.1
Ash Street to Belmont Avenue	-0.8	-0.4	-0.1	-0.2	-0.2
Belmont Avenue to Carleton Street	-0.6	-0.3	-0.1	0.0	0.0
Carleton Street to No. Arlington Culvert	-0.9	-0.5	-0.1	0.0	0.0
Belmont Street (123) to Warren Avenue	-0.6	-0.3	0.0	0.0	0.0
Warren Avenue to Allen Street	-0.6	-0.2	0.0	0.0	0.0
Allen Street to White Avenue	-0.4	-0.1	-0.1	0.0	0.0
White Avenue to Railroad Bridge	-0.5	-0.2	-0.1	0.0	0.0
Railroad Bridge to Otis Street	-0.4	-0.1	-0.1	0.0	0.0
Otis Street to Grove Street	-0.3	-0.2	-0.1	0.0	0.0
Grove Street to Pine Avenue	-0.4	-0.2	-0.1	-0.1	-0.1
Pine Avenue to Perkins Avenue	-0.7	-0.3	-0.2	-0.2	-0.2
Perkins Avenue to Plain Street	-0.8	-0.6	-0.4	-0.4	-0.4
Plain Street to Sargent's Way	-0.7	-0.7	-0.6	-0.7	-0.7
Sargent's Way to WWTF/K-Mart Plaza	-0.2	-0.2	-0.1	-0.2	-0.2
Order of Magnitude Cost - $4 million (with a range between $3 million and $5.8 million)					

Notes:
1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

Table 8-18. Composite Alternative 2 (EB-2, UP-2 & UP-3)

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Elmwood Avenue to Prospect Street	-1.0	-0.7	0.0	0.0	0.0
Prospect Street to Pleasant Street	-1.1	-0.7	0.0	0.0	0.0
Pleasant Street to Moraine Street Conduit	-1.1	-1.0	-0.1	0.0	0.0
Moraine Street Conduit to Ash Street	-0.8	-0.7	-0.3	-0.1	0.0
Ash Street to Belmont Avenue	-0.8	-0.4	-0.1	-0.2	-0.1
Belmont Avenue to Carleton Street	-0.6	-0.3	-0.1	0.0	0.0
Carleton Street to No. Arlington Culvert	-0.9	-0.5	-0.1	0.0	0.0
Belmont Street (123) to Warren Avenue	-0.6	-0.3	0.0	0.0	0.0
Warren Avenue to Allen Street	-0.6	-0.2	0.0	0.0	0.0
Allen Street to White Avenue	-0.4	-0.1	-0.1	0.0	0.0
White Avenue to Railroad Bridge	-0.5	-0.2	-0.1	0.0	0.0

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Railroad Bridge to Otis Street	-0.4	-0.1	-0.1	0.0	0.0
Otis Street to Grove Street	-0.3	-0.2	-0.1	0.0	0.0
Grove Street to Pine Avenue	-0.4	-0.2	-0.1	-0.1	0.0
Pine Avenue to Perkins Avenue	-0.7	-0.3	-0.2	-0.2	-0.1
Perkins Avenue to Plain Street	-0.8	-0.6	-0.4	-0.4	-0.1
Plain Street to Sargent's Way	-0.8	-0.8	-0.7	-0.7	-0.6
Sargent's Way to WWTF/K-Mart Plaza	-0.4	-0.4	-0.3	-0.4	-0.4
Order of Magnitude Cost - $5.4 million (with a range between $4 million and $7.8 million)					

Notes:
1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

Table 8-19. Composite Alternative 3 (EB-3 & UP-2)

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Elmwood Avenue to Prospect Street	-1.3	-0.9	-0.1	0.0	0.0
Prospect Street to Pleasant Street	-1.4	-1.0	-0.1	0.0	0.0
Pleasant Street to Moraine Street Conduit	-1.5	-1.4	-0.3	-0.2	-0.1
Moraine Street Conduit to Ash Street	-1.3	-1.0	-0.8	-0.6	-0.1
Ash Street to Belmont Avenue	-1.3	-0.7	-0.3	-0.3	-0.1
Belmont Avenue to Carleton Street	-1.1	-0.9	-0.3	-0.1	-0.1
Carleton Street to No. Arlington Culvert	-1.2	-1.1	-0.3	0.0	-0.1
Belmont Street (123) to Warren Avenue	-0.8	-0.5	-0.2	-0.1	-0.1
Warren Avenue to Allen Street	-0.8	-0.4	-0.2	-0.1	0.0
Allen Street to White Avenue	-0.5	-0.2	-0.7	-0.1	0.0
White Avenue to Railroad Bridge	-0.7	-0.3	-0.8	-0.2	0.0
Railroad Bridge to Otis Street	-0.6	-0.2	-0.4	-0.2	-0.1
Otis Street to Grove Street	-0.5	-0.3	-0.2	-0.1	-0.1
Grove Street to Pine Avenue	-0.5	-0.3	-0.2	-0.1	-0.1
Pine Avenue to Perkins Avenue	-0.9	-0.5	-0.3	-0.2	-0.1
Perkins Avenue to Plain Street	-1.0	-0.8	-0.4	-0.5	-0.2
Plain Street to Sargent's Way	-0.9	-0.8	-0.7	-0.7	-0.6
Sargent's Way to WWTF/K-Mart Plaza	-0.4	-0.2	-0.2	-0.2	-0.2
Order of Magnitude Cost - $7.3 million (with a range between $5.4 million and $10.5 million)					

Notes:
1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

Table 8-20. Composite Alternative 4 (EB3, UP-2 & UP-3)

Location in River System	2-Year Avg. WSE Change	10-Year Avg. WSE Change	50-Year Avg. WSE Change	100-Year Avg. WSE Change	500-Year Avg. WSE Change
Elmwood Avenue to Prospect Street	-1.3	-1.0	-0.1	0.0	0.0
Prospect Street to Pleasant Street	-1.4	-1.0	-0.1	0.0	0.0
Pleasant Street to Moraine Street Conduit	-1.5	-1.4	-0.3	-0.2	-0.1
Moraine Street Conduit to Ash Street	-1.3	-1.0	-0.8	-0.6	-0.1
Ash Street to Belmont Avenue	-1.3	-0.7	-0.3	-0.3	-0.1
Belmont Avenue to Carleton Street	-1.1	-0.9	-0.3	-0.1	-0.1
Carleton Street to No. Arlington Culvert	-1.2	-1.1	-0.3	0.0	0.0
Belmont Street (123) to Warren Avenue	-0.8	-0.5	-0.2	-0.1	-0.1
Warren Avenue to Allen Street	-0.8	-0.4	-0.2	-0.1	0.0
Allen Street to White Avenue	-0.5	-0.2	-0.7	-0.1	0.0
White Avenue to Railroad Bridge	-0.7	-0.3	-0.8	-0.2	0.0
Railroad Bridge to Otis Street	-0.6	-0.2	-0.4	-0.2	-0.1
Otis Street to Grove Street	-0.5	-0.3	-0.2	-0.1	-0.1
Grove Street to Pine Avenue	-0.5	-0.3	-0.2	-0.2	-0.1
Pine Avenue to Perkins Avenue	-0.9	-0.5	-0.3	-0.2	-0.1
Perkins Avenue to Plain Street	-1.0	-0.8	-0.4	-0.5	-0.2
Plain Street to Sargent's Way	-0.9	-0.9	-0.7	-0.8	-0.7
Sargent's Way to WWTF/K-Mart Plaza	-0.5	-0.4	-0.4	-0.4	-0.4
Order of Magnitude Cost - $8.7 million (with a range between $6.4 million and $12.5 million)					

Notes:

1. Salisbury Brook extends from Elmwood Avenue to its confluence with Trout Brook, which occurs just upstream of Grove Street. At this point, the Salisbury Brook becomes the Salisbury Plain River.
2. All water surface elevation (WSE) changes within table are in feet.

While the installation of a gate at Ellis Brett (EB-2) results in the highest benefit to cost ratio as a stand-alone flood reduction option during the 2- and 10-year floods, it was determined that:

- combining with the increase in flood storage at Ellis Brett through excavation (EB-1) would further enhance flood reduction benefits throughout the length of the river during the 2- and 10-year floods (i.e. within the Belmont Avenue area) as well as provide flood reduction benefits throughout the river system for the 50-year flood (i.e. within the section of the Brook between Allen Street and Perkins Street resulting in the removal of the White Avenue Bridge crossing from the 50-year inundation area); and
- combining with flood restoration improvements between Plain Street and a point approximately 1,400 feet downstream of Sargent's Way (UP-2) would further reduce flood levels downstream of Pine Avenue (i.e. at commercial properties located along the River between Plain Street and Sargent's Way) during all analyzed flood events. The greatest flood inundation limit reductions, however, would be noted during the 10-year flood. This would be beneficial in improving access to high value commercial properties along Meadowbrook Lane as well as reducing flooding for a few commercial properties with lower assessed value on opposite side of river (on river right).

Figure 8-35 illustrates the comparative reductions in the extent of flooding within the Belmont Avenue area of frequent flooding during the 2-year flood due to the installation of only a gate structure at Ellis Brett Pond (EB-2) (in light blue) versus the installation of a gate structure combined with excavation at Ellis Brett Pond (EB-3) (in dark blue). The current extent of the 2-year inundation area is shown in red. While there is not a major reduction in the number of structures inundated due to increasing the amount of storage in Ellis Brett Pond, there is a relatively significant reduction in the amount of roadway flooding along Silver Road and Belmont Avenue.

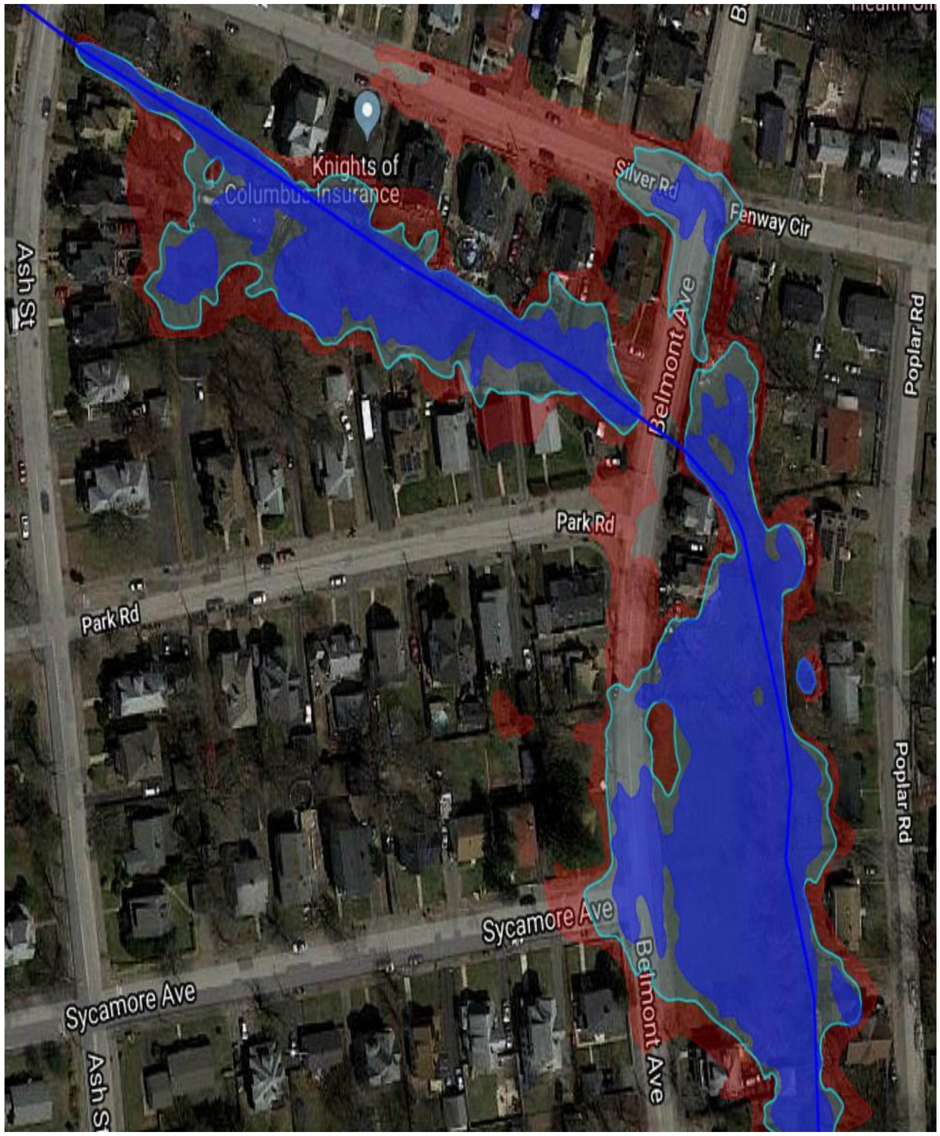


Figure 8-35. Flood Inundation Limit Comparison in Belmont Area for 2-Year Flood: gate-only option (EB-2; light blue), gate plus excavation option (EB-3; dark blue) and existing conditions (red).

Figure 8-36 illustrates the primary area of benefit when floodplain restoration between Plain Street and Sargent's Way (UP-2) is added to the combined Ellis Brett option (EB-3). Reductions in the extent of flooding yield benefits for the area along Meadowbrook Road and the commercial areas along the River between Plain Street and Sargent's Way during the 10-year flood.

Figure 8-36. Flood Inundation Limit Comparison Between Plain Street and Sargent's Way during 10-Year Flood Along Meadowbrook Lane and Adjacent Commercial Properties: gate-only option (EB-2; light blue), Composite Alternative 3 (blue) and existing conditions (red).

Of the two preferred composite alternatives, the order of magnitude opinion of cost for Composite Alternative 1 is approximately $4 million while the order of magnitude opinion of cost for Composite Alternative 3 is approximately $7.3 million. Although Composite Alternative 3 is more costly, the added reductions in flood elevations of approximately 6 inches throughout the frequently flooded Belmont Area during the 2-year flood (in addition to the reduction in roadway flooding) and greater than 7 inch reductions between White Avenue and Montello Street during the 50-year flood may justify the added cost as well as help the flood resiliency of this area due to projected increases in flooding as a result of climate change. Alternatively, the City could elect to pursue Composite Alternative 1 with property buy-outs within these frequently flooded properties within the Belmont Area (as discussed in more detail in Section 2.2).

For flood inundation area comparison purposes, refer to **Appendix D** for present-day pre-condition flood boundaries and Composite Alternative 3 flood inundation boundaries for all flood events analyzed. Composite Alternative 3 represents the greatest reduction in flood inundation areas. The extent of flood reductions would be less for Composite Alternative 1.

8.6 Impact of Increased Precipitation due to Climate Change

To assess the impacts that increased precipitation would have on flooding experienced throughout the Salisbury Brook/Salisbury Plain River riverine system with and without the proposed flood reduction improvements proposed under Composite Alternative 3, 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.

Future increases in flood flows during the analyzed flood events will result in the following impacts to water surface elevations in Salisbury Brook and Salisbury Plain River downstream of Cross Pond:

Table 8-21. Projected Impacts of Increased Precipitation on Salisbury Brook and Salisbury Plain River With and Without Composite Alternative 3 Flood Reduction Improvements

Change in Flood Elevation for Various Storm Conditions due to Projected Increased Precipitation	Without Composite Alternative 3 Flood Reduction Improvements		With Composite Alternative 3 Flood Reduction Improvements	
	Salisbury Brook	Salisbury Plain River	Salisbury Brook	Salisbury Plain River
2-Year Flood Elevation	0.5 feet	0.6 feet	-0.4 feet	-0.1 feet
10-Year Flood Elevation	1.1 feet	0.8 feet	0.2 feet	0.3 feet
50-Year Flood Elevation	0.6 feet	0.9 feet	0.5 feet	0.6 feet
100-Year Flood Elevation	0.5 feet	0.9 feet	0.4 feet	0.6 feet
500-Year Flood Elevation	0.7 feet	1.1 feet	0.6 feet	0.9 feet

The flood reduction measures proposed under Composite Alternative 3 result in reduced impacts from increased precipitation, with smaller increases in flood elevation for all flood events as compared to not implementing the composite flood reduction improvements.

When future climate predictions for increased precipitation are considered relative to present-day existing flood conditions in Brockton, the beneficial reductions from the composite nature-based flood reduction improvements will be most significant for the projected 2- and 10-year floods. During these flood events, the improvements will still yield between 6 to 11 inch reductions in Salisbury Brook flood levels throughout the Belmont area (between Moraine Street and Spring Street) during the projected 2-year flood and between 1 to 4 inch reductions during the 10-year flood (when compared to present day flood levels), even after increased precipitation is accounted for. There will also be between 2 to 12 inch reductions in Salisbury Plain River flood levels between Plain Street and Sargent's Way during the projected 2-year flood and between 1 to 7 inch reductions during the 10-year flood (when compared to present-day flood levels).

In larger flood events such as the 50-, 100-, and 500-year floods, the increases in river flood level due to increased precipitation will be less than if no nature-based flood reduction measures were installed when comparing the large flood events, but the minor reductions shown in the models relative to current conditions will likely not be realized as they will be negated by the increased precipitation.

Figure 8-37. Pre- versus Post-Restoration Flood Extent Comparison for the Projected/Future 2-Year Flood Event in Belmont Neighborhood

Refer to **Appendix D** for HEC-RAS model output summary data and water surface profiles that reflect comparisons between current and future 2-, 10-, 50-, 100-, and 500-year flood events. Full-scale figures showing the extents of flooding for the 2-year through 500-year future floods are also included.

8.7 Other Restoration Options for Consideration

8.7.1 Channel Deepening along Ellsworth Avenue & Associated Structural Improvement Options

During a field visit, it was noted that there was an approximate 2.4-foot drop at the inlet/entrance of the long underground culvert that extends beneath E.B. Keith Athletic Field. After further review of previous reports and files, it was noted that the United States Army Corps of Engineers (USACE) had also noted this drop and suggested the elimination of this drop in its 1975 Flood Protection Study to increase flood protection throughout the Ellsworth area. Removing this vertical drop would allow for an increased channel depth between Carleton Street and the underground culvert's entrance as the channel bottom would need to be re-graded with a constant (and slightly greater) slope. Consequently, this increase in channel depth and slope would result in an increased flood storage and conveyance capacity within the channel between the downstream end of the Carleton Street culvert and the entrance to the E.B. Keith Athletic Field culvert. In order to achieve this, however, the channel side walls along both sides of this approximate 900-foot section of the Brook would need to be reconstructed. Reconstruction would likely require stabilizing and/or reinforcing the base of the walls with a sheet pile system or similar approach. Channel bottom material would need to be excavated and removed and the concrete deck covering the channel between North Arlington Street and Newbury Street would need to be removed and replaced. Therefore, the cost for a project of this magnitude (including permitting, design, and construction administration) would likely range between $4.6 million and $8.9 million. Based on preliminary hydraulic analyses, flood reductions would be localized to this section of the Salisbury Brook between Carleton Street and the entrance to the E.B. Athletic Field culvert. Such reductions would range between 0.29 feet and less for those flood events that result in the overtopping of the channel's

Figure 8-38. 2.4-Foot Drop at E.B. Keith Athletic Field Culvert Entrance

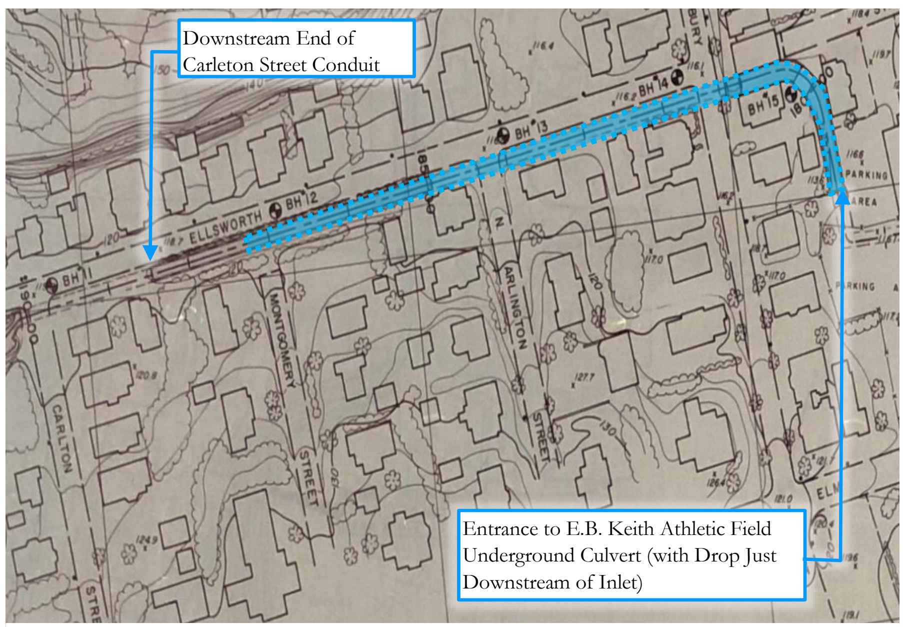


Figure 8-39. Theoretical Limits for Channel Deepening Along Ellsworth

walls such as the 10- through 100-year flood events. These reductions would not result in the removal of any structures from their respective flood inundation areas or have significant flood protection benefits. As a result, this option would not have a favorable benefit to cost ratio and is not recommended.

8.7.2 French Brook Flood Reduction

In order to determine the maximum flood benefits that could be realized by increasing floodplain storage within the low-lying area within the French B rook Watershed as approximately shown in **Figure 8-40**, the clearing of an approximate 8.1-acre upland area and subsequent removal of 82,400 cubic yards of material to enhance floodplain storage was analyzed. This upland material would be removed from between El. 76.0 feet and El. 82.0 feet (NAVD88). Restoration activities would occur primarily on undeveloped portions of three privately owned properties Parcel 081-067 ($24,400), Parcel 081-072 ($301,500), Parcel 081-269 ($12,600). These properties are all owned by one owner. The following table shows calculated reductions in flood level reductions based on preliminary modeling.

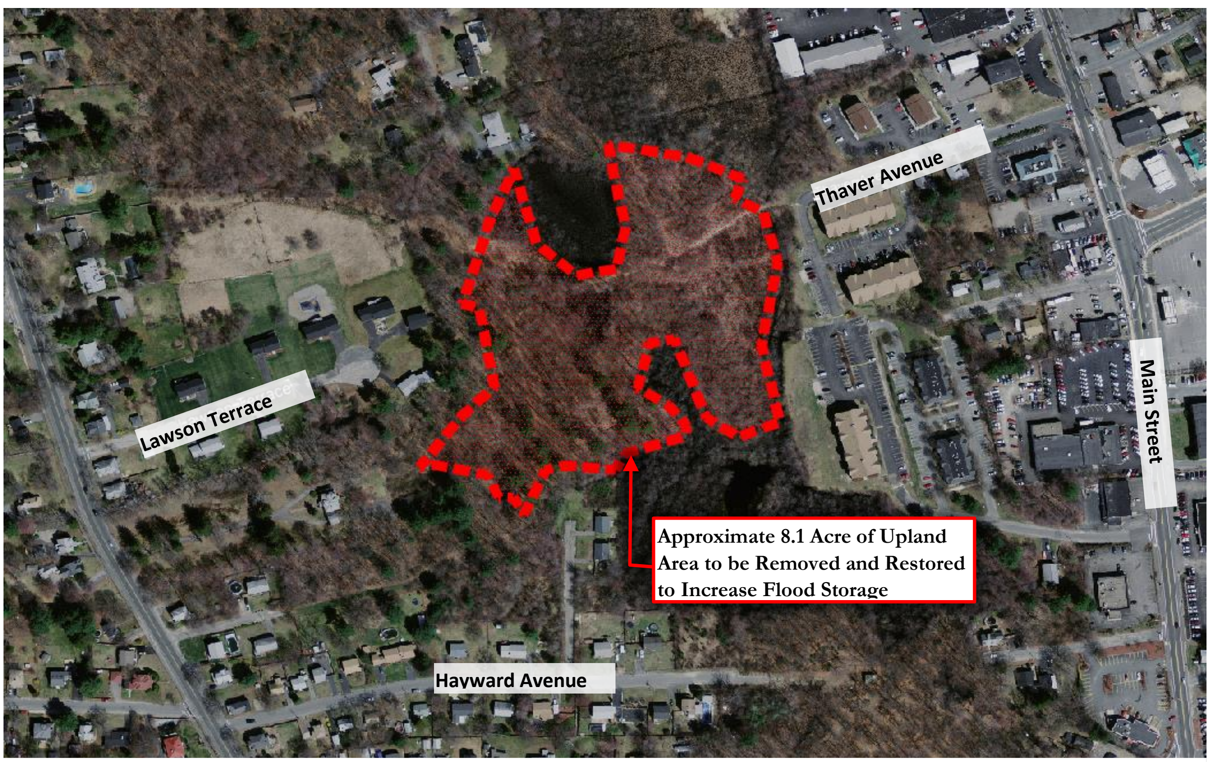


Figure 8-40. Approximate Area of Floodplain Restoration to Increase Flood Storage for French Brook

Table 8-22. French Brook Alternative Flood Reduction Summary

Flood Event	Pre-Restoration Brook WSE (NAVD88)	Post-Restoration Brook WSE (NAVD88)	Change
2-Year Flood	78.07 feet	77.12 feet	-0.95 feet
10-Year Flood	79.19 feet	78.32 feet	-0.87 feet
50-Year Flood	80.38 feet	79.66 feet	-0.72 feet
100-Year Flood	80.87 feet	80.27 feet	-0.60 feet
500-Year Flood	81.45 feet	81.23 feet	-0.22 feet

Since clearing is proposed within wetland buffer areas, wetlands approval will be required. Additionally, a right-of-way easement and a drain easement bisect the area where restoration is proposed. As a result, additional research would be required to confirm that such easements would not preclude proposed restoration activities. In terms of relative benefits to costs, it appears that this restoration alternative would not only provide flood reductions as listed in **Table 8-22** but it would also eliminate the overtopping of Main Street in the vicinity of its intersection with Brookside Avenue during the 100-year flood and assist in minimizing flooding that occurs in frequently flooded properties along French Brook in the vicinity of Brookside Avenue and Monarch Street. However, the order of magnitude opinion of cost to perform such restoration activities was estimated to be approximately $5.8 million (with a likely range between $4.3 million and $8.3 million). As a result, the benefit to cost ratio for this option would be relatively low. Hydraulic analysis summary data and more detailed breakdown of order of magnitude opinions of cost for this alternative is provided in **Appendix D**.

8.7.3 K-mart Plaza Flood Reduction

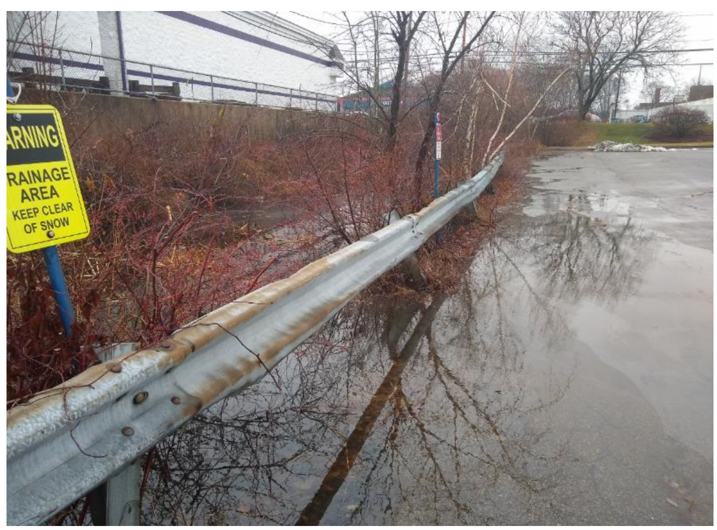


Figure 8-41. Flooding of K-Mart Plaza Channel during December 2019 Rainfall Event

Flooding in K-Mart Plaza is largely influenced by flooding of the Salisbury Plain River that creates a backflow scenario, preventing adequate drainage from the plaza. Runoff that is collected by the swale in the northeastern portion of the plaza is discharged to the river via a closed-conduit system that conveys runoff beneath Main Street. As flood levels rise within the river, the plaza's outflow culvert becomes submerged and the full-flow capacity of the culvert is substantially reduced. Based on a comparison between flood levels in the river and the approximate topography of the plaza that was obtained from LiDAR, it appears that river flood levels exceed ground elevations that exist within the plaza during all flood events analyzed. The following table provides a summary of flooding that is likely experienced within the plaza during the 2-, 10-, 50-, 100- and 500-year flood events.

Table 8-23. K-Mart Plaza Current Flooding Summary

Flood Event	River WSE (NAVD88)	Extent of Plaza Parking Lot Inundation Parking Area Elevation Varies Between El. 68.0 to El. 72.0[1]	Extent of Building First Floor Inundation - El. 72.0
2-Year Flood	69.1 feet	34.2% of Paved On-site Areas (Primarily along Swale in Northeastern Portion of Site) – Maximum Depth of 1.1 feet	None
10-Year Flood	70.0 feet	46.5% of Paved On-Site Areas (Primarily along Swale in Northeastern Portion of Site and Rear Access Driveway) – Maximum Depth of 2.0 feet	None
50-Year Flood	71.0 feet	67.4% of Paved On-Site Areas (Significant Portion of Main Parking Area and Rear Access Driveway) – Maximum Depth of 3.0 feet	None
100-Year Flood	71.2 feet	71.1% of Paved On-Site Areas (Significant Portion of Main Parking Area and Rear Access Driveway) – Maximum Depth of 3.2 feet	None
500-Year Flood	72.3 feet	88.4% of Paved On-Site Areas (Significant Portion of Main Parking Area and Rear Access Driveway) – Maximum Depth of 4.3 feet	None

Note:
[1] Percentages exclude area covered by on-site building structures. On-site building structures cover approximately 25.4% of the developed portion of the plaza.

Figure 8-42. Existing Flood Inundation Limit at K-Mart Plaza

Figure 8-42 provides a visual representation of the extent of flooding currently experienced within the plaza during these flood events. The structures generally remain outside of all flooded areas. Alternative UP-3, outlined above, may convey some benefit to the flooding at the K-Mart Plaza as it will likely lower flood elevations within the Plaza by four inches or less. However, because this will not substantially improve on-site flooding conditions it is likely more cost-effective to improve the resiliency of the Plaza by reconfiguring the Plaza site itself and converting unused parking areas (ideally furthest away from building structures and immediately adjoining the site's existing drainage swale) to stormwater infiltration and/or low-lying detention areas that would provide added flood storage. Areas that would remain as parking could be raised to minimize flooding frequency. A cut/fill analysis would need to be performed to ensure that there would not be a net loss in flood storage (within the plaza) and a parking study/analysis would be required to determine the minimum number of parking spaces that the Plaza could be designed with to still support its parking needs while eliminating unused or excess parking. It is understood that the Plaza has currently lost its primary tenant. When the Plaza is renovated and redeveloped, the parking lot should be designed with integrated green infrastructure and reduced impervious area and such studies/analyses should be performed. Green spaces created for stormwater management on the property can be integrated into the landscape design to simultaneously provide additional amenities for the property and neighborhood.

8.7.4 Trout Brook Flood Reduction

As noted in Section 1.1.2, Trout Brook contributes significant flows to the Salisbury Plain River system. Based on the results of our hydraulic analyses, flow contributions from Trout Brook constitute approximately 60% to 62% of total flow through the Salisbury Plain River downstream of its confluence with the Salisbury Brook for the analyzed flood events. In terms of actual peak flow runoff rates, Trout brook discharges approximately 465 cfs, 750 cfs, 1,120 cfs, 1,300 cfs, and 1,855 cfs to the river system during the 2-, 10-, 50-, 100-, and 500-year flood events respectively. This influx of water, in turn, largely diminishes the positive impact of flood reduction strategies applied in the upper watershed (i.e. at Ellis Brett Pond or other areas along Salisbury Brook upstream of its confluence with Trout Brook). While this study focused on the main riverine corridor through the City, this scenario demonstrates the importance of applying stormwater management and flooding resilience approaches City-wide, so that excess stormwater runoff is managed as much as possible within the watershed where it originates, rather than accumulating in downstream waterbodies where it presents an overwhelming challenge.

One of the flood prone neighborhoods along Trout Brook includes a former CSX freight rail yard which has been abandoned. The City of Brockton has completed a plan to use the redevelopment of this site as an opportunity for a larger urban renewal project that attracts commercial and residential investment in this neighborhood and creates an economic opportunity for the city as a whole. This economic development opportunity simultaneously provides an opportunity to reduce flooding risk to the neighborhoods around and downstream of the development. Proposed open space areas along the stream corridor could be designed for multi-purpose use as walkable access from surrounding neighborhoods, accessible green space for the community centered around the urban stream, and, during flood events, safe storage, detention, and conveyance of floodwaters.

It is likely that upstream flood management projects and floodplain restoration along Trout Brook could significantly increase the downstream gains of various alternatives considered in this report. A preliminary analysis that assumed reduced inflows from Trout Brook indicated that reduction to 80% of the current peak flows would yield roughly 0.2 to 0.4 foot reductions in flood levels throughout the downstream reach of Salisbury Plain River (between Grove Street and Plain Street) for the 2-year flood and 0.2 to 0.8 foot reductions for the 10-year flood. **Figure 8-43** illustrates the reduction in the 10-year water surface profile between Grove Street and Plain Street under this assumed reduced-flow condition. These improvements would increase the effectiveness of proposed floodplain restoration projects along Salisbury Plain River. Detailed modeling and analysis of the Trout Brook system is needed to evaluate and quantify the impacts of proposed upstream flood management solutions and determine whether 20% reductions in peak flows from Trout Brook could realistically be achieved.

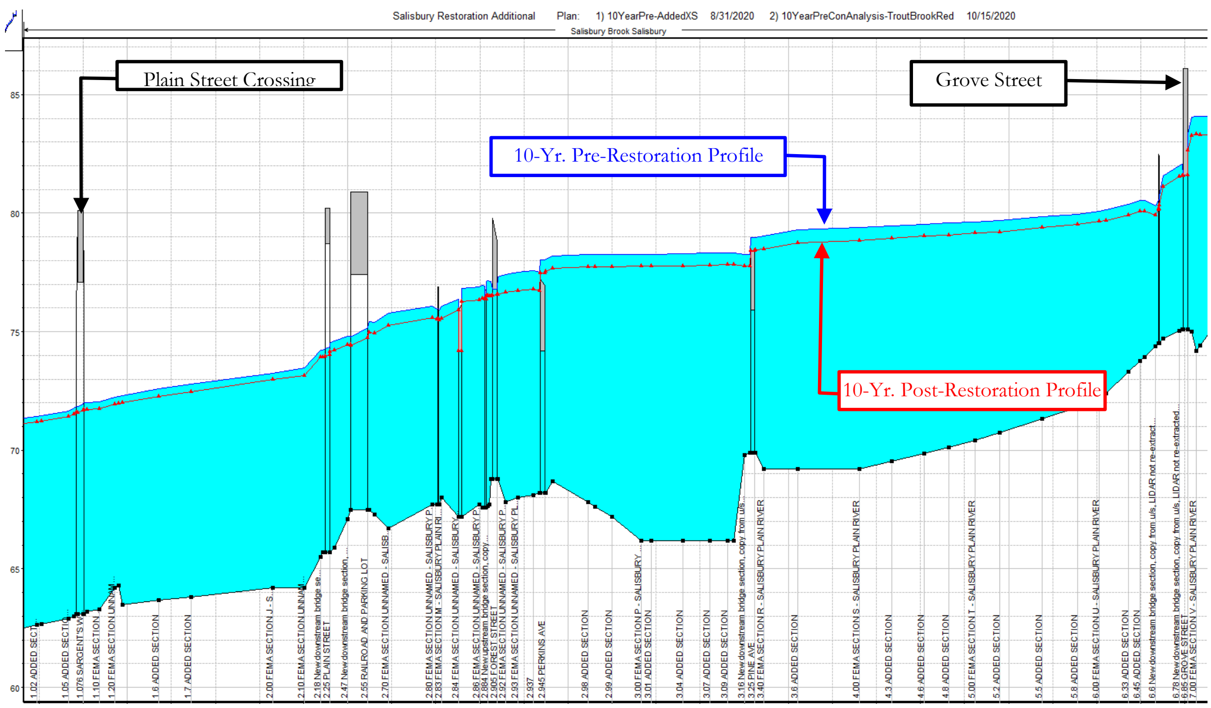


Figure 8-43. Pre- and Post-Trout Brook Flow Reduction 10-Year Water Surface Elevation Profile Comparison (Grove Street to Plain Street)

8.7.5 Buy-Outs

The City of Brockton has already established a precedent for buy-out of residences that experience repetitive losses due to more frequent flooding (such as the 2- and 10-year floods); several homes were purchased and demolished along Belmont Avenue north of Spring Street. We conducted modeling of floodplain restoration for this now vacant area, but since the scale of the properties was small, no significant benefits were seen. Nonetheless, while selective buy-outs may not yield sites for successful restoration that has broader downstream benefits, relocating land uses out of the floodplain can be a cost-effective means of reducing risk, simply by moving people in flood-prone homes and buildings to higher ground. Reclaimed property in the floodplain can then be reclaimed for open space and recreation, with new uses designed to be floodable (e.g., floodable parks). Buy-outs could be considered as an additional resilience strategy for certain flood-prone areas of the City where flooding cannot be adequately addressed by the proposed floodplain restoration alternatives or if the installation of a gate at Ellis Brett Pond proves to be the only economically justifiable flood restoration option (in other words if increasing storage at Ellis Brett and performing floodplain restoration in the area of Plain Street and Sargent's Way is determined to not be economically justifiable). Specific areas/properties that may be candidates for buy-outs for these reasons due to their locations in the 2- or 10-year flood inundation areas include:

- Belmont Neighborhood – If the excavation at Ellis Brett Pond as outlined in Composite Alternative 3 is not preferred due to its added cost, the following properties within the Belmont Avenue area could be considered for potential buy-out (the approximate 2019 assessed property value is provided in parentheses): Parcel 048-205 ($221,200), Parcel 048-330 ($205,500), Parcel 048-337 ($339,500), Parcel 048-338 ($449,300), Parcel 048-355 ($340,000), Parcel 048-041 ($229,600), Parcel 048-046 ($245,300), Parcel 048-047 ($211,000), Parcel 048-048 ($261,200), Parcel 048-051 ($266,600), Parcel 048-015 ($225,500), Parcel 048-126 ($363,400), and Parcel 048-127 ($267,900). These parcels represent properties where the structure would be located outside of the 10-year flood inundation area if excavation at Ellis Brett was performed. These 2019 assessed property values total approximately $3.6 million. This value is relatively equivalent to the estimated order of magnitude opinion of cost (of $3.5 million) to increase storage at Ellis Brett. However, it must be noted that the amount of storage approximated at Ellis Brett is likely the maximum that could be achieved. So if increasing storage at Ellis Brett is determined by City to be preferred option to further enhance flood reduction benefits in the Belmont Neighborhood, the extent of excavation could be slightly reduced in order to provide a more beneficial benefit to cost ratio.
- Commercial Area between Plain Street and Sargent's Way – If floodplain restoration in the Plain Street to Sargent's Way area is not preferred due to its added cost (approximated to be $3.4 million), the following commercial properties could be considered for potential buy-out (the approximate 2019 assessed property value is provided in parentheses): Parcel 118-014 ($274,200) and Parcel 118-015 ($236,600). These 2019 assessed property values total approximately $500K. While this value is substantially lower than the cost of floodplain restoration in this area, one of the primary benefits to floodplain restoration in this area is the elimination of flooding along Meadowbrook Road in the vicinity of the High Point Treatment Center and within the Treatment Center's parking lot during the 10-year flood.

Even with the flood reduction improvements proposed, the following properties located within the 2- or 10-year flood inundation limits should also be considered for buy-out since such improvements result in only minimal flood reduction benefits:

- Belmont Neighborhood - The following properties contain structures within the limits the 10-year flood in the Belmont Neighborhood (the approximate 2019 assessed property value is provided in parentheses): Parcel 048-298 ($281,300), Parcel 048-341 ($421,300), Parcel 048-331 ($180,400), Parcel 048-332 ($208,200), Parcel 048-333 ($396,900), Parcel 048-334 ($255,800), Parcel 048-335 ($260,200), Parcel 048-336 ($387,400), Parcel 048-032 ($231,600), Parcel 048-033 ($227,400), Parcel 048-034 ($245,400), Parcel 048-035 ($2,800), Parcel 048-040 ($286,700), and Parcel 048-042 ($461,600). These 2019 assessed property values total approximately $3.8 million.
- Otis Street Area - The following properties contain structures within the limits the 10-year flood in the Otis Street area (the approximate 2019 assessed property value is provided in parentheses): Parcel 136-031 ($271,300) and Parcel 136-032 ($506,500).
- Hudson Street- The following properties contain structures within the limits the 10-year flood located at the western end of Hudson Street (the approximate 2019 assessed property value is provided in parentheses): Parcel 129-084 ($247,100), Parcel 129-085 ($246,200), and Parcel 129-082 ($250,000).
- Riverview Street Neighborhood – The following properties contain structures or access driveways located in the 10-year flood inundation area (the approximate 2019 assessed property

value is provided in parentheses): Parcel 124-001 ($87,300), Parcel 124-002 ($215,800), Parcel 124-018 ($260,600), Parcel 124-019 ($138,900), and Parcel 124-020 ($262,000). These 2019 assessed property values total approximately $970K.

Creation of new housing stock may be necessary in order to provide appropriate and affordable relocation sites. Redevelopment projects and economic development planning should consider the potential need for housing and/or commercial properties outside of flood-prone areas.

To more accurately identify structures that would be damaged by frequent flooding, flood elevation certificates or surveyed first floor elevations of structures located within or near the 2- and 10-year flood inundation areas would be needed. The first floor elevations (as determined by survey) could then be compared to the computed 2- and 10-year flood peak water surface elevations to confirm which structures would be inundated.

9 Conclusions & Future Work

The results of our hydrologic and hydraulic analyses of the Salisbury Brook/Salisbury Plain River riverine system show a general agreement with areas of flooding that were communicated to Fuss & O'Neill in an Initial Stakeholder Meeting conducted on September 10, 2019. The majority of areas where frequent or repetitive flooding has been reported along the Salisbury Brook and Salisbury Plain River are captured within the modeled flood inundation boundaries for the 2-, 10-, and/or 50-year flood events.

In developing the hydraulic model for the Salisbury Brook and Salisbury Plain River, it was observed that the amount of floodplain storage along the Salisbury Plain River (downstream of the confluence with Trout Brook) is significantly greater than that along Salisbury Brook (upstream of the confluence with Trout Brook). Floodplain storage along Salisbury Brook is limited due to development extending directly up to the banks of the Brook. In fact, there are several locations along Salisbury Brook where the channel is restricted by concrete sidewalls. As a result, there are more locations along Salisbury Brook (than Salisbury Plain River) where flooding occurs more frequently (i.e. during the 2-year and 10-year flood events).

There are a few areas, however, along the Salisbury Plain River where flooding does occur rather frequently (i.e. during the 2-year and 10-year flood events). These locations include properties along French Brook (in the vicinity of Brookside Avenue and Monarch Street) and the K-Mart Plaza. Flooding along French Brook appears to be due to the urbanized nature of the waterway and an inadequately sized discharge culvert that conveys flow from French Brook into the Salisbury Plain River. Backwater impacts from the Salisbury Plain River do not appear to be a significant issue for French Brook during the 2-year flood event, but do appear to be a significant issue for larger flood events. Flooding at the K-Mart plaza during the 2-year flood (as well as larger floods) appears to be the result of backwater impacts which prevent drainage from K-Mart from making its way out into the Salisbury Plain River.

The nature-based approaches presented here attempt to identify additional flood storage areas along Salisbury Brook and the Salisbury Plain River to address ongoing flooding impacts along the river corridor that are only expected to worsen with climate change. In addressing this problem, the City is very cognizant of its downstream neighbors, and recognizes that moving water through the City faster, while it might alleviate some flooding concerns, would only cause greater impacts for downstream communities. The overall approach highlighted here therefore focuses on detaining and infiltrating water higher up in the watershed, working with nature-based solutions to limit downstream flooding impacts.

Based on the results of our modeling, the preferred alternative combines two key approaches:

- Utilizing the City's dams, in particular, Ellis Brett Pond Dam, to hold additional water during storm events and control its release, and
- Applying floodplain restoration approaches that entail excavating key properties along the river corridor to create additional floodplain storage at locations where Salisbury Plain River is currently restricted by channelized banks and/or development within the floodplain. Additional flood storage capacity will allow water to be spread out and slowed, reducing peak flows and velocities.

While the installation of a gate at Ellis Brett results in the highest benefit to cost ratio as a stand-alone flood reduction option during the 2- and 10-year floods, it was determined that:

- combining with the increase in flood storage at Ellis Brett through excavation would further enhance flood reduction benefits throughout the length of the river system (Brook and River) during the 2- and 10-year floods (i.e. within the Belmont Avenue area) as well as provide flood reduction benefits throughout the river system for the 50-year flood (i.e. within the section of the Brook between Allen Street and Perkins Street resulting in the removal of the White Avenue Bridge crossing from the 50-year inundation area); and
- combining with flood restoration improvements between Plain Street and a point approximately 1,400 feet downstream of Sargent's Way would further reduce flood levels downstream of Pine Avenue (i.e. at commercial properties located along the River between Plain Street and Sargent's Way) during all analyzed flood events. The greatest flood inundation limit reductions, however, would be noted during the 10-year flood. This would be beneficial in improving access to high value commercial properties along Meadowbrook Lane as well as reducing flooding for a few commercial properties with lower assessed value on opposite side of river (on river right)

Despite these benefits, the preferred alternative does not address all known flooding areas. Additional flood protection measures will be needed to round out a comprehensive resiliency strategy for the City. Proposed additional measures include property buy-outs to facilitate planned retreat, relocating land uses at flood-prone properties to more protected areas of the City as part of a planned redevelopment strategy.

Based on a preliminary estimate of the order of magnitude opinion of cost for increasing flood storage in Ellis Brett Pond, it appears that the cost of this effort will be nearly equivalent to the cost of buying-out properties that would be removed from the 10-year flood inundation area due to the inclusion of floodplain storage. Therefore, the City could alternatively consider buying out these properties if a more detailed analysis reveals that excavating to increase storage to the anticipated volume at Ellis Brett Pond cannot be achieved or proves to be more costly or difficult to permit. This solution would not provide the same benefits in terms of reduced roadway flooding, but would prevent potential damages to life and property at the affected residences.

Similarly, it was also noted that the benefit to cost ratio associated with implementing floodplain restoration between Plain Street and Sargent's Way may not be as favorable as it appears if flooding along Meadowbrook Lane is less detrimental to access to the High Point Treatment Center, Meadowbrook Campus, and adjacent commercial properties than modeling indicates. However, proposed flood restoration measures within this stretch of the River would eliminate flooding of this roadway during events up to and including the 10-year flood as well as significantly reduce or eliminate the inundation of two commercial properties located at the eastern end of Watson Street. This option is expected to provide added resiliency to higher value/assessed properties along this section of the River such as the Brockton Area Transit Administrative Office property and Campello High Rise Apartments.

Finally, the results of our hydraulic and hydrologic modeling indicate the importance of attenuating floodwaters upstream in the City's other watersheds, before they contribute to the flows in the Salisbury Plain River. Green infrastructure applications for on-site stormwater management should be explored throughout the City, and particularly during any future redevelopment of the K-Mart Plaza or Westgate Mall properties. Additional study and modeling should focus on developing appropriate, parallel nature-based solutions for Trout Brook and other areas of the City in order to develop a comprehensive approach to nature-based flood protections.

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