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RESILIENT NEW YORK FLOOD MITIGATION INITIATIVE

EIGHTEENMILE CREEK, ERIE COUNTY, NEW YORK

Prepared for:

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Project Team:

OBG Part of Ramboll

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HIGHLAND PLANNING

RESILIENT NEW YORK FLOOD MITIGATION INITIATIVE
EIGHTEENMILE CREEK, ERIE COUNTY, NEW YORK

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IN NOVEMBER 2018, NEW YORK STATE GOVERNOR ANDREW CUOMO COMMITTED FUNDING TO UNDERTAKE ADVANCED MODELING TECHNIQUES AND FIELD ASSESSMENTS OF 48 FLOOD-PRONE STREAMS TO IDENTIFY PRIORITY PROJECTS AND ACTIONS TO REDUCE COMMUNITY FLOOD AND ICE JAM RISKS, WHILE IMPROVING HABITAT. THE OVERALL GOAL OF THE PROGRAM IS TO MAKE NEW YORK STATE MORE RESILIENT TO FUTURE FLOODING.

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ACRONYMS/ABBREVIATIONS

1-D	1-Dimensional
2-D	2-Dimensional
AC	Acres
ACE	Annual Chance Flood Event
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
BFE	Base Flood Elevation
BRIC	Building Resilient Infrastructure and Communities
CDBG	Community Development Block Grants
CFA	Consolidated Funding Applications
CFR	Code of Federal Regulations
CFS	Cubic Feet per Second (ft3/s)
CRISSP	Comprehensive River Ice Simulation System
CRRA	Community Risk and Resiliency Act
CRREL	Cold Regions Research and Engineering Laboratory
CRS	Community Rating System
CSC	Climate Smart Communities
CWSRF	Clean Water State Revolving Fund
DEM	Digital Elevation Model
DHS	Department of Homeland Security
DRRA	Disaster Recovery Reform Act of 2018
ECDEP	Erie County Department of Environment and Planning
ECDHSES	Erie County Department of Homeland Security and Emergency Services
ECSWCD	Erie County Soil and Water Conservation District
EPA	Environmental Protection Agency

EPG	Engineering Planning Grant
EWP	Emergency Watershed Protection
FDD	Freezing Degree-Day
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Maps
FIS	Flood Insurance Study
FMA	Flood Mitigation Assistance
FT	Feet
GIS	Geographic Information System
GLS	Generalized Least-Squares
GSE	Gomez & Sullivan Engineers
H&H	Hydrologic and Hydraulic
HEC	Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HMGP	Hazard Mitigation Grant Program
HSGP	Homeland Security Grant Program
HUD	Department of Housing and Urban Development
IPaC	Information for Planning and Consultation
LF	Linear Feet
LOMR	Letter of Map Revision
LP3	Log-Pearson III
NAVD88	North American Vertical Datum of 1988
NCEI	National Centers for Environmental Information
NFHL	National Flood Hazard Layer
NFIP	National Flood Insurance Program
NGTOC	National Geospatial Technical Operations Center
NHD	National Hydrography Dataset
NRCS	Natural Resources Conservation Services
NWI	National Wetlands Inventory
NYS	New York State
NYSDEC	New York State Department of Environmental Conservations
NYSDHSES	New York State Division of Homeland Security and Emergency Services
NYSDOT	New York State Department of Transportation
NYSEFC	New York State Environmental Facilities Corporation
NYSOEM	New York State Office of Emergency Management
NYSOGS	New York State Office of General Services
NYSOPRHP	New York State Office of Parks, Recreation, and Historic Places
PDM	Pre-Disaster Mitigation
RAMBOLL	OBG, Part of Ramboll
RC	Circularity Ratio
RE	Elongation Ratio
RF	Form Factor

RICEN	River Ice Simulation Model
RL	Repetitive Loss
ROM	Rough Order of Magnitude
SCS	Soil Conservation Service
SFHA	Special Flood Hazard Areas
SHSP	State Homeland Security Program
SQ MI	Square Miles (mi2)
SRL	Severe Repetitive Loss
USACE	United States Army Corps of Engineers
USGS	United States Geologic Service
USSCS	United States Soil Conservation Service
WQIP	Water Quality Improvement Project

1. INTRODUCTION

1.1 HISTORICAL INITIATIVES

Flood mitigation has historically been an initiative in western New York and in the Eighteenmile Creek watershed. The Eighteenmile Creek watershed has not historically been a source of major flooding events in Erie County, NY. A significant reason for the lack of large historical damages and losses from flooding in the Eighteenmile Creek watershed is due to the implementation of flood protection measures within the Towns of Hamburg and Boston, which comprises the majority of the Eighteenmile Creek watershed area.

In the Town of Hamburg, zoning ordinances have prevented substantial development in floodplain areas. Any construction in the floodplain is limited to lot sizes of two acres or more. As a result, the density of buildings within the floodplain has remained low and prevented worsening flood problems within the basin due to the reduction in flood flow capacity caused by buildings and infrastructure. In addition, retention basins have been installed in some areas of the Town to retain excessive storm drainage. These retention basins help to reduce peak discharges during storm events and to compensate for the increased runoff caused by development in the watershed (FEMA 2001).

In the Town of Boston, two small dams were constructed along Eighteenmile Creek. These dams retain water during low flow events; however, because water generally passes around or over the dams, they do not afford protection from flood events greater than the 10-year recurrence interval (FIA 1981).

1.2 FLOODPLAIN DEVELOPMENT

General recommendations for high risk floodplain development follow three basic strategies:

1. Remove the flood prone facilities from the floodplain
2. Adapt the facilities to be flood resilient under repetitive inundation scenarios
3. Develop nature-based mitigation measures (e.g., floodplain benches, constructed wetlands, etc.) to lower flood stages in effected areas
4. Up-size bridges and culverts to be more resilient to ice jams, high flow events, and projected future flood flows due to climate change in effected areas

In order to effectively mitigate flooding along substantial lengths of a watercourse corridor, floodplain management should restrict the encroachment on natural floodplain areas. Floodplains act to convey floodwaters downstream, mitigate damaging velocities, and provide areas for sediment to accumulate safely. The reduction in floodplain width of one reach of a stream, often leads to the increase in flooding upstream or downstream. During a flood event, a finite amount of water with an unchanging volume must be conveyed and, as certain conveyance areas are encroached upon, floodwaters will often expand into other sensitive areas.

A critical evaluation of existing floodplain law and policies should be undertaken to evaluate the effectiveness of current practices and requirements within this watershed. Local floodplain regulations should be consistent with the National Flood Insurance

Program (NFIP) and Federal Emergency Management Agency (FEMA) regulations since the Towns of Hamburg and Boston are participating communities in the NFIP and should involve a floodplain coordinator and a site plan review process for all proposed developments. This review should be in accordance with local regulations and the NFIP requirements, which require the community to determine if any future proposed development could adversely impact the floodplain or floodway resulting in higher flood stages and sequentially greater economic losses to the community.

1.3 RESILIENT NY INITIATIVE

In November of 2018, New York State (NYS) Governor Andrew Cuomo announced the Resilient NY Initiative in response to devastating flooding in communities across the State in the preceding years. Flood mitigation studies were commissioned using advanced modeling techniques and field assessments to identify priority projects in 48 flood-prone streams, develop state-of-the-art studies to reduce flooding and ice jams, and to improve ecological habitats in the watersheds (NYSGPO 2018). The Eighteenmile Creek watershed was chosen as a study site for this initiative.

The New York State Department of Environmental Conservation is responsible for implementing the Resilient NY program with contractual assistance from the New York State Office of General Services (NYSOGS). High-priority watersheds were selected based on several factors, such as frequency and severity of flooding and ice jams, extent of previous flood damage, and susceptibility to future flooding and ice-jam formations (NYSGPO 2018).

The Resilient NY flood studies will identify the causes of flooding within each watershed and develop, evaluate, and recommend effective and ecologically sustainable flood and ice-jam hazard mitigation projects. Proposed flood mitigation measures will be identified and evaluated using hydrologic and hydraulic modeling to quantitatively determine flood mitigation recommendations that would result in the greatest flood reductions benefits. In addition, the flood mitigation studies incorporate the latest climate change forecasts and assess ice-jam hazards where jams have been identified as a threat to public health and safety.

This report is not intended to address detailed design considerations for individual flood mitigation alternatives. The mitigation alternatives discussed are conceptual projects that have been initially developed and evaluated to determine their flood mitigation benefits. A more in-depth engineering design study would still be required for any mitigation alternative chosen to further define the engineering project details. However, the information contained within this study can inform such in-depth engineering design studies and be used in the application of state and federal funding and/or grant programs.

The goals of the Resilient NY Initiative are to:

1. Perform comprehensive flood and ice jam studies to identify known and potential flood risks in flood-prone watersheds
2. Incorporate climate change predictions into future flood models

3. Develop and evaluate flood hazard mitigation alternatives for each flood-prone stream area, with a focus on ice-jam hazards

The overarching purpose of the initiative is to recommend a suite of flood and ice-jam mitigation projects that local municipalities can undertake to make their community more resilient to future floods. The projects should be affordable, attainable through grant funding programs, able to be implemented either individually or in combination in phases over the course of several years, achieve measurable improvement at the completion of each phase, and fit with the community way of life.

The flood mitigation and resiliency study for Eighteenmile Creek began in July of 2019 and a final flood mitigation study was issued in October of 2020.

2. DATA COLLECTION

2.1 INITIAL DATA COLLECTION

Hydrological and meteorological data were obtained from readily available state and federal government databases, including ortho-imagery, flood zone maps, streamflow, precipitation, flooding and ice jam reports. Historical flood reports, newspaper articles, social media posts, community engagement meeting notes, and geographic information system (GIS) mapping were used to identify stakeholder concerns, produce watershed maps, and identify current high-risk areas. New York State Community Risk and Resiliency Act (NYSDEC 2018) draft guidelines, New York State Department of Transportation (NYSDOT) bridge and culvert standards, and United States Geologic Service (USGS) *FutureFlow Explorer* v1.5 (USGS 2016) and *StreamStats* v4.3.11 (USGS 2017) software were used to develop current and future potential discharges and bankfull widths and depths at various points along the stream channel. Hydrologic and hydraulic (H&H) modeling was performed previously, as part of the 1980 and 1981 FEMA Flood Insurance Study (FIS) for the Towns of Hamburg and Boston, respectively. Updated H&H modeling was performed in this study using the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS) v5.0.7 (USACE 2019) software to determine water stage at current and potential future levels for high risk areas and to evaluate the effectiveness of proposed flood mitigation strategies. These studies and data were obtained and used, all or in part, as part of this effort. Appendix A is a summary listing of data and reports collected.

Stationing references are based on the USGS National Hydrography Dataset (NHD) for Eighteenmile Creek (USGS 2020) and the ESRI ArcMap 10.7 GIS software (ESRI 2019), except when referring to the FEMA FIS where stationing values from the flood profiles in the FIS reports are used (FEMA 2019b).

2.2 PUBLIC OUTREACH

An initial project kickoff meeting was held on July 16, 2019, with representatives of the NYSDEC, NYSOGS, New York State Office of Emergency Management (NYSOEM), OBG, Part of Ramboll (Ramboll), Gomez & Sullivan Engineers (GSE), Highland Planning, USACE, Town of West Seneca, Town of Amherst, Town of Concord, Erie County Soil and Water Conservation District (ECSWCD), Erie County Department of Environment and Planning (ECDEP), Erie County Department of Homeland Security and Emergency Services (ECDHSES), and the Buffalo-Niagara Waterkeepers (Appendix D). At the project kickoff meeting, project specifics including background, purpose, funding, roles, and timelines were discussed. Discussions included a variety of topics, including:

- Firsthand accounts of past flooding events
- Identification of specific areas that flooded in each community, and the extent and severity of flood damage
- Information on post-flood efforts, such as temporary floodwalls

This outreach effort assisted in the identification of current high-risk areas to focus on during the future flood risk assessments.

2.3 FIELD ASSESSMENT

Following the initial data gathering and agency meetings, field staff from Ramboll undertook field data collection efforts with special attention given to high risk areas in the Towns of Hamburg and Boston as identified in the initial data collection process. Initial field assessments of Eighteenmile Creek were conducted in July 2019. Information collected during field investigations included the following:

- Rapid "windshield" river corridor inspection
- Photo documentation of inspected areas
- Measurement and rapid hydraulic assessment of bridges, culverts, and dams
- Geomorphic classification and assessment, including measurement of bankfull channel widths and depths at key cross sections
- Field identification of potential flood storage areas
- Wolman pebble counts
- Characterization of key stream bank failures, head cuts, bed erosion, aggradation areas, and other unstable stream channel features
- Preliminary identification of potential flood hazard mitigation alternatives, including those requiring further analysis

Included in Appendix B is a copy of the Stream Channel Classification Form, Field Observation Form for the inspection of bridges and culverts, and Wolman Pebble Count Form, as well as a location map of where field work was completed. Appendix C is a photo log of select locations within the river corridor. The collected field data was categorized, summarized, indexed, and geographically located within a GIS database. This GIS database will be made available to the NYSDEC and NYSOGS upon completion of the project.

All references to “right bank” and “left bank” in this report refer to "river right" and "river left," meaning the orientation assumes that the reader is standing in the river looking downstream.

3. WATERSHED CHARACTERISTICS

3.1 STUDY AREA

The Eighteenmile Creek watershed study areas lies entirely within Erie County, NY encompassing the areas between the Towns of Hamburg, Boston, and Concord. The creek flows in a general north/northwest direction with its headwaters in the Town of Concord, and passes through the Towns of Boston, Hamburg, and Eden and the Village of Hamburg before emptying into Lake Erie (Figure 3-1). Within the Eighteenmile Creek watershed, the Town of Boston was chosen as the target area for this study due to their historical and recent flooding issues and the hydrologic conditions of the creek. Figure 3-2 depicts the stream stationing along the entire reach of Eighteenmile Creek in Erie County, NY. Figure 3-3 depicts the stream stationing along Eighteenmile Creek within the study area in the Town of Boston.

The Town of Boston occupies 35 square miles in the south-central portion of Erie County in northwestern New York state, and is approximately 24-miles southeast of the City of Buffalo. The Town is bounded by the Town of Orchard Park to the north, Town of Concord to the northwest, Town of North Collins to the southwest, Town of Colden to the east, and the Town of Eden to the west. Eighteenmile Creek enters the Town of Boston from its headwaters in the Town of Concord in the south at an elevation of 970-ft and flows to the north. The Town of Boston is considered to be part of the Allegheny Plateau, and Eighteenmile Creek lies in the valley between the east and west hills of the Plateau, which rise to elevations of 1,650 feet and 1,550 feet, respectively. The valley and Eighteenmile Creek floodplain located through the Town of Boston ranges in width from 2,000 to 3,000 feet. There has been no major historic flooding on Eighteenmile Creek in the Town of Boston; however, recently there have been minor floods within the Town that have caused damages to property and infrastructure as a result of ice jams and heavy rains (FIA 1981, NCEI 2020).

The Town of Hamburg occupies 41.4 square miles in the central-west section of Erie County in northwestern New York state, and is approximately 15-miles south of the City of Buffalo. The Villages of Blasdell and Hamburg lie within the limits of the Town of Hamburg, and the Town is bounded by the City of Lackawanna to the north, the Town of Orchard Park to the east, the Towns of Eden and Evans to the south, and Lake Erie to the west. The Town of Hamburg is primarily part of the Erie-Ontario Plain with land that rises quickly from the lake to an elevation of approximately 600-feet, and then steeply rises again in the southeast corner of town. All streams in the town drain into Lake Erie, including Eighteenmile Creek (FEMA 2001). Eighteenmile Creek experiences random flooding along the southern portions of the Town of Hamburg due primarily to heavy rains and sediment and debris back up (DCDDP 2005).

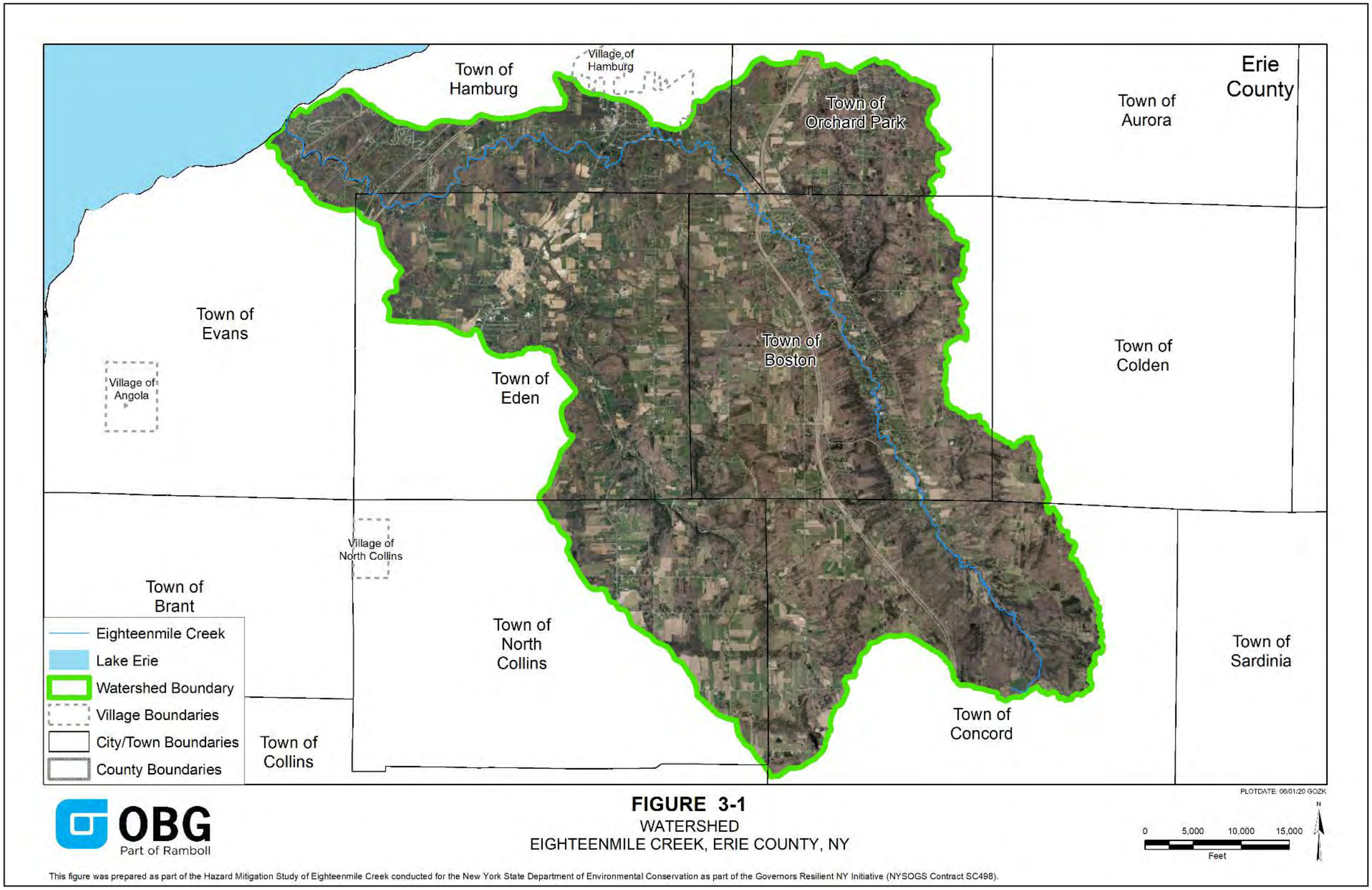

Figure 3-1. Eighteenmile Creek Watershed, Erie County, NY.

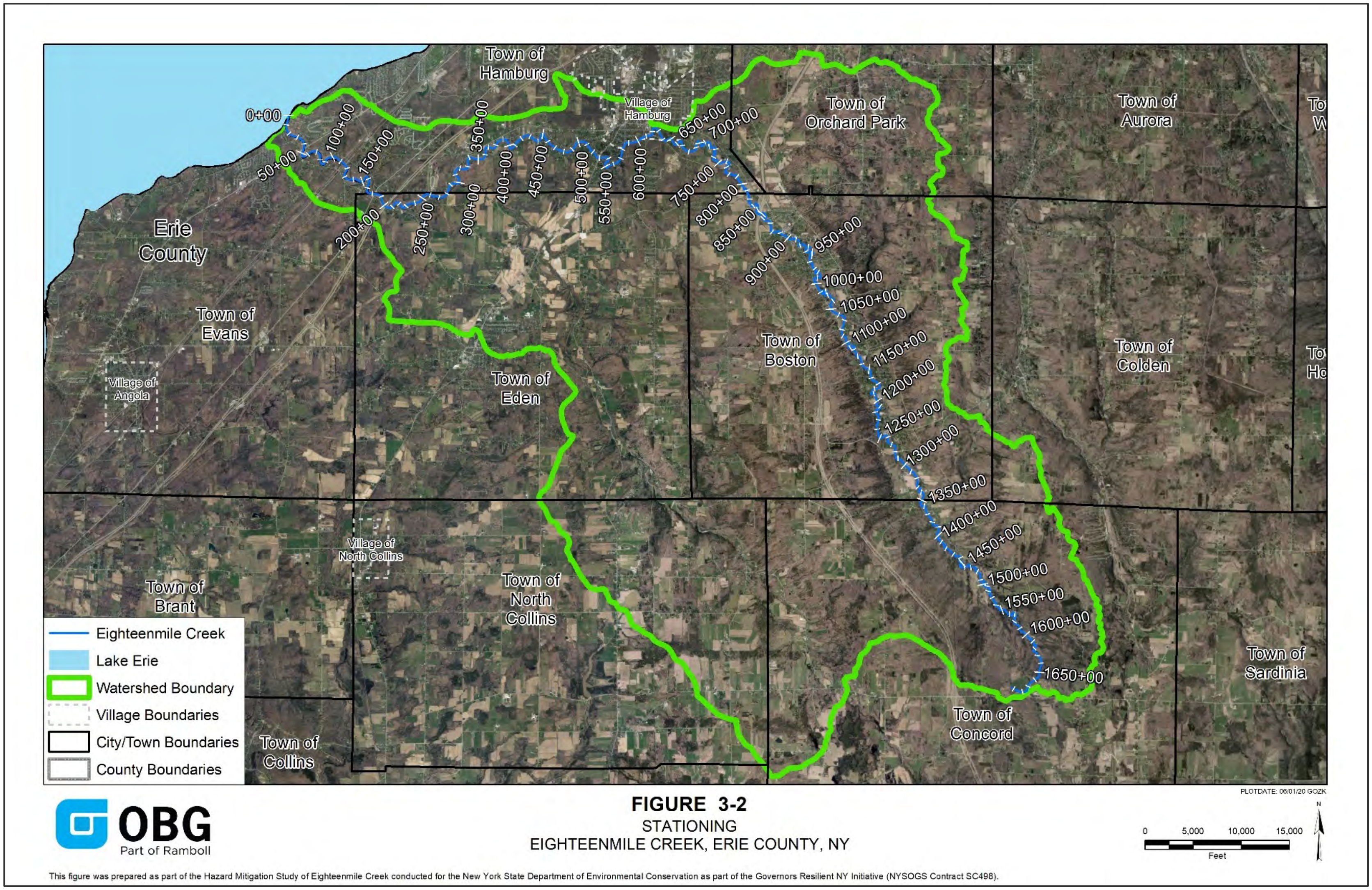

Figure 3-2. Eighteenmile Creek Stationing, Erie County, NY.

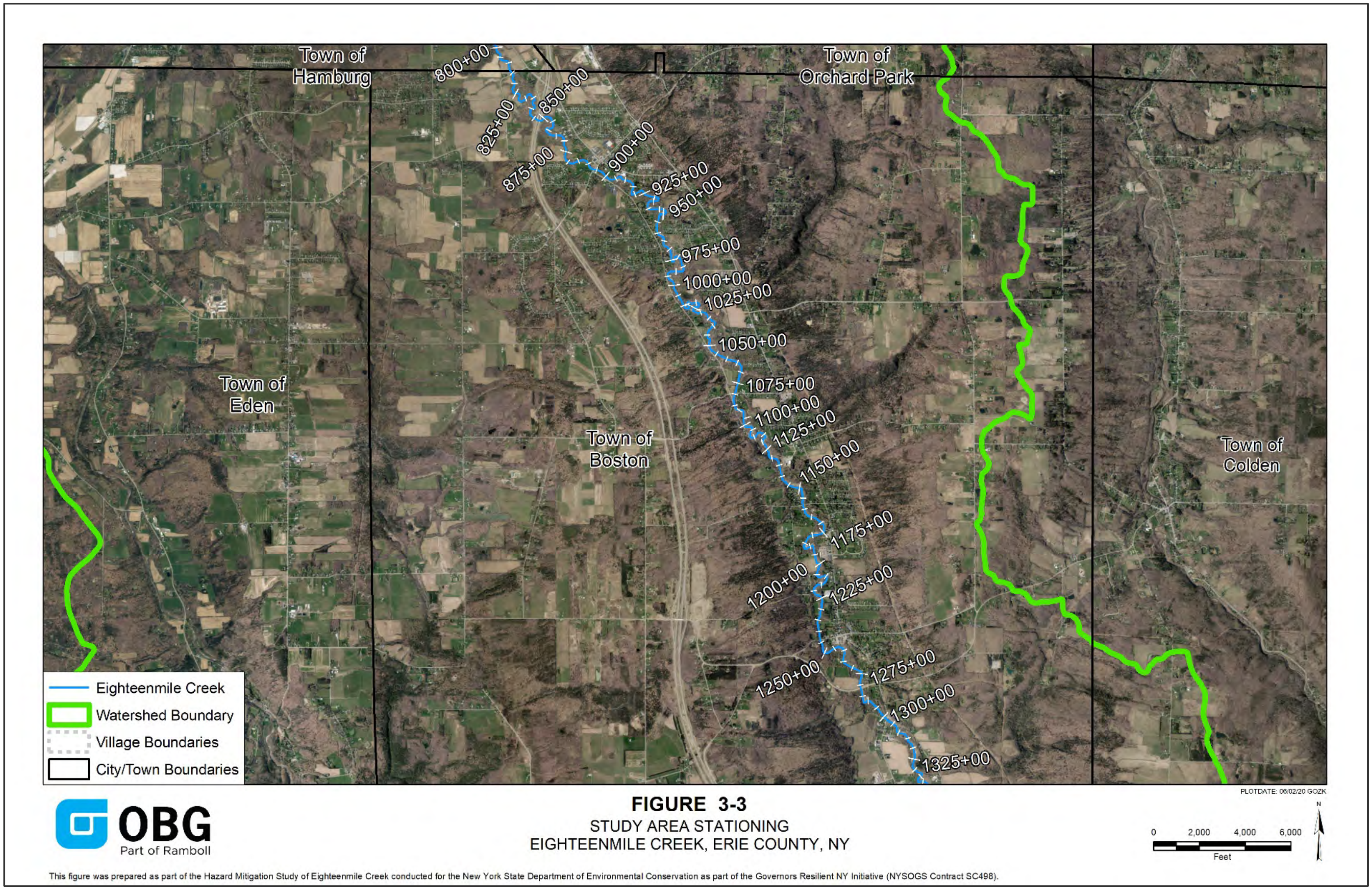

Figure 3-3. Eighteenmile Creek Study Area Stationing, Erie County, NY.

3.2 ENVIRONMENTAL CONDITIONS

An overview of the environmental and cultural resources within the Eighteenmile Creek watershed was compiled using the following online tools:

- **Environmental Resource Mapper** – The Environmental Resource Mapper is a tool used to identify mapped federal and state wetlands, state designated significant natural communities, and plants and animals identified as endangered or threatened by the NYSDEC (NYSDEC 2020) (https://gisservices.dec.ny.gov/gis/erm/)
- **National Wetlands Inventory (NWI)** – The NWI is a digital map database available on the Environmental Resource Mapper that provides information on the "status, extent, characteristics and functions of wetlands, riparian, and deepwater habitats" (NYSDEC 2020)
- **Information for Planning and Consultation (IPaC)** – The IPaC database provides information about endangered/threatened species and migratory birds regulated by the U.S. Fish and Wildlife Service (USFWS 2020) (https://ecos.fws.gov/ipac/)
- **National Register of Historic Places** – The National Register of Historic Places lists historic places worthy of preservation, as authorized by the National Historic Preservation Act of 1966 (NPS 2014) (https://www.nps.gov/maps/full.html?mapId=7ad17cc9-b808-4ff8-a2f9-a99909164466)

3.2.1 Wetlands

The State Regulated Freshwater Wetlands database shows the approximate location of wetlands regulated by New York state. The check zone is a 100-foot buffer zone around the wetland in which the actual wetland may occur. According to the Environmental Resource Mapper, several state-regulated freshwater wetlands are located within the Eighteenmile Creek watershed. The National Wetlands Inventory was reviewed to identify national wetlands and surface waters (Figure 3-4). The Eighteenmile Creek watershed includes riverine habitats, freshwater emergent wetlands, and freshwater forested/shrub wetlands (NYSDEC 2020).

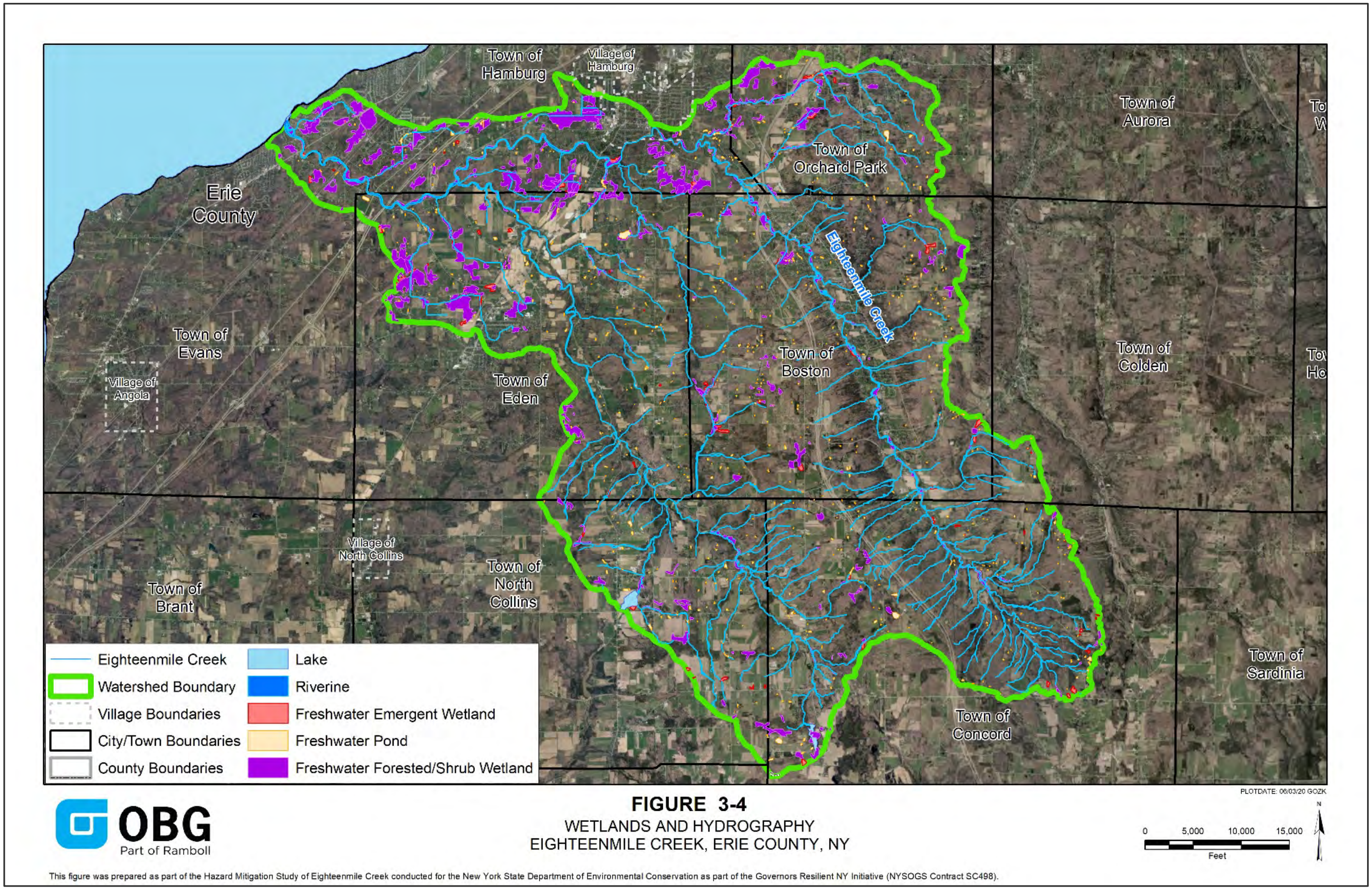

Figure 3-4. Eighteenmile Creek Wetlands and Hydrography, Erie County, NY.

3.2.2 Sensitive Natural Resources

The Eighteenmile Creek watershed contains a significant natural community, as mapped by the Environmental Resource Mapper (NYSDEC 2020). The significant natural communities identified are a Rich hemlock-hardwood peat swamp and a Black spruce-tamarack bog, which are within the system of Freshwater Nontidal Wetlands and the subsystem Forested Peatlands (NYSDEC 2020).

3.2.3 Endangered or Threatened Species

The Environmental Resource Mapper shows that the watershed basin is within the vicinity of bats listed as Endangered or Threatened by the NYSDEC (Figure 3-5). The NYSDEC Regional Office should be contacted to determine the potential presence of the species identified (NYSDEC 2020).

The USFWS IPaC results for the project area list one threatened species, the Northern Long-eared Bat (Myotis septentrionalis). No critical habitat has been designated for the species at this location (USFWS 2020) (https://ecos.fws.gov/ipac/). The migratory bird species listed in Table 1 are transient species that may pass over, but are not known to nest within the project area.

Table 1. UFWS IPaC Listed Migratory Bird Species

(Source: USFWS 2020)			
Common Name	**Scientific Name**	**Level of Concern**	**Breeding Season**
American Golden-plover	*Pluvialis dominica*	BCC Rangewide (CON)2	Breeds elsewhere
Bald Eagle	*Haliaeetus leucocephalus*	Non-BCC Vulnerable1	Breeds Sep 1 to Aug 31
Black-billed Cuckoo	*Coccyzus erythropthalmus*	BCC Rangewide (CON)2	Breeds May 15 to Oct 10
Black-capped Chickadee	*Poecile atricapillus practicus*	BCC-BCR3	Breeds Apr 10 to Jul 31
Bobolink	*Dolichonyx oryzivorus*	BCC Rangewide (CON)2	Breeds May 20 to Jul 31
Canada Warbler	*Cardellina canadensis*	BCC Rangewide (CON)2	Breeds May 20 to Aug 10
Dunlin	*Calidris alpina arcticola*	BCC-BCR3	Breeds elsewhere
Golden Eagle	*Aquila chrysaetos*	Non-BCC Vulnerable1	Breeds Jan 1 to Aug 31
Golden-winged Warbler	*Vermivora chrysoptera*	BCC Rangewide (CON)2	Breeds May 1 to Jul 20
Lesser Yellowlegs	*Tringa flavipes*	BCC Rangewide (CON)2	Breeds elsewhere
Red-headed Woodpecker	*Melanerpes erythrocephalus*	BCC Rangewide (CON)2	Breeds May 10 to Sep 10
Rusty Blackbird	*Euphagus carolinus*	BCC Rangewide (CON)2	Breeds elsewhere
Semipalmated Sandpiper	*Calidris pusilla*	BCC Rangewide (CON)2	Breeds elsewhere
Snowy Owl	*Bubo scandiacus*	BCC Rangewide (CON)2	Breeds elsewhere
Wood Thrush	*Hylocichla mustelina*	BCC Rangewide (CON)2	Breeds May 10 to Aug 31
Yellow-bellied Sapsucker	*Sphyrapicus varius*	BCC-BCR3	Breeds May 10 to Jul 15

1. This is not a Bird of Conservation Concern (BCC) in this area but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities.
2. This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska (CON).
3. This is a Bird of Conservation Concern (BCC) only in particular Bird Conservation Regions (BCRs) in the continental USA.

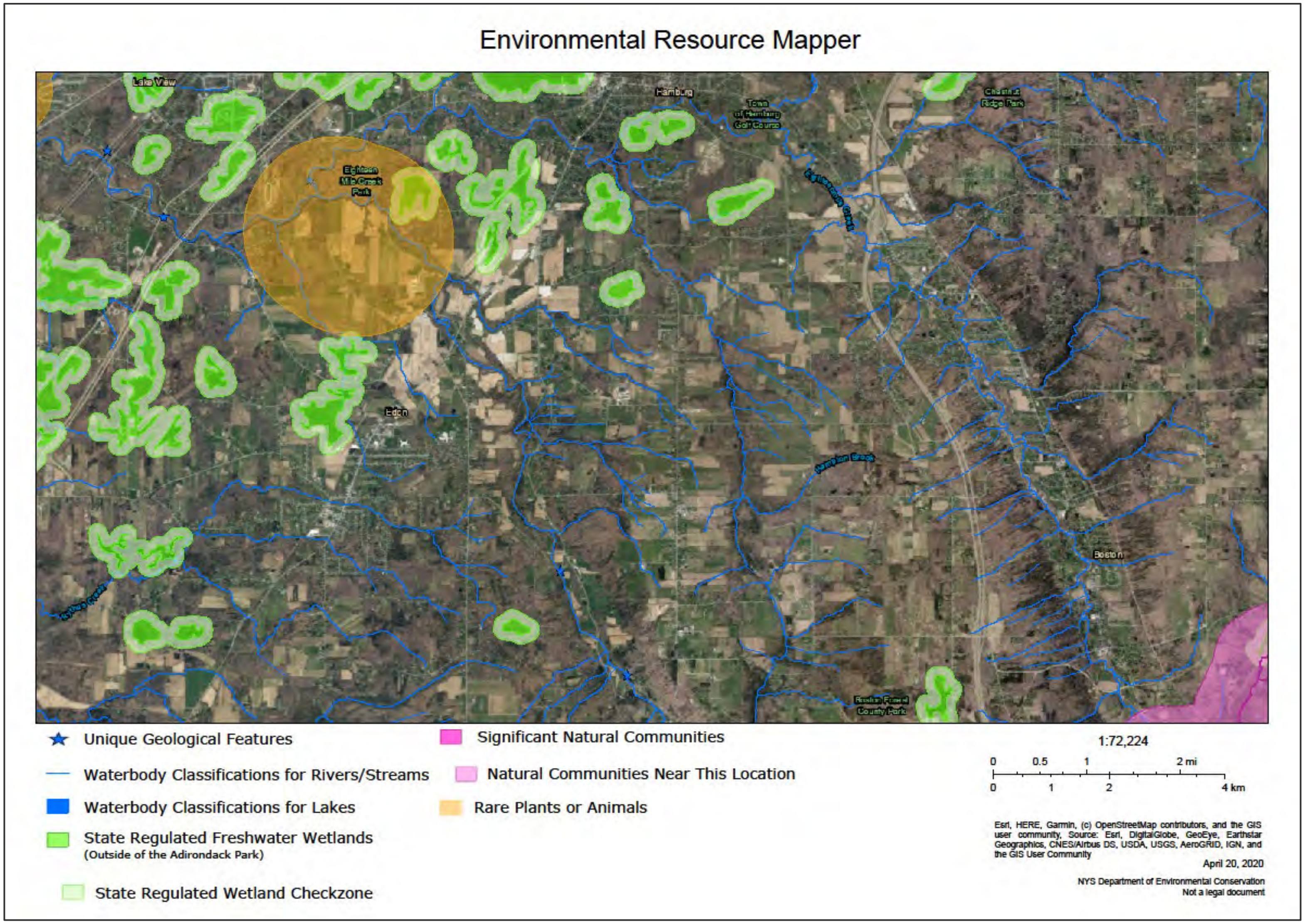

Figure 3-5. Significant Natural Communities and Rare Plants or Animals, Eighteenmile Creek, Erie County, NY.

3.2.4 Cultural Resources

According to the National Register of Historic Places, Eighteenmile Creek is located near the Graycliff Conservancy (6472-6482 Lakeshore Road), Hamburg Main Street Historic District (11 through 235 Main Street), and Eden Mills Historic District (Eden Valley, NY). The boundaries of the resource are shown in the figure below (Figure 3-6). Consultation with New York State Office of Parks, Recreation, and Historic Places (NYSOPRHP) should be performed to identify the potential presence of archeological resources and the subsequent need to perform a cultural resources investigation (NPS 2014).

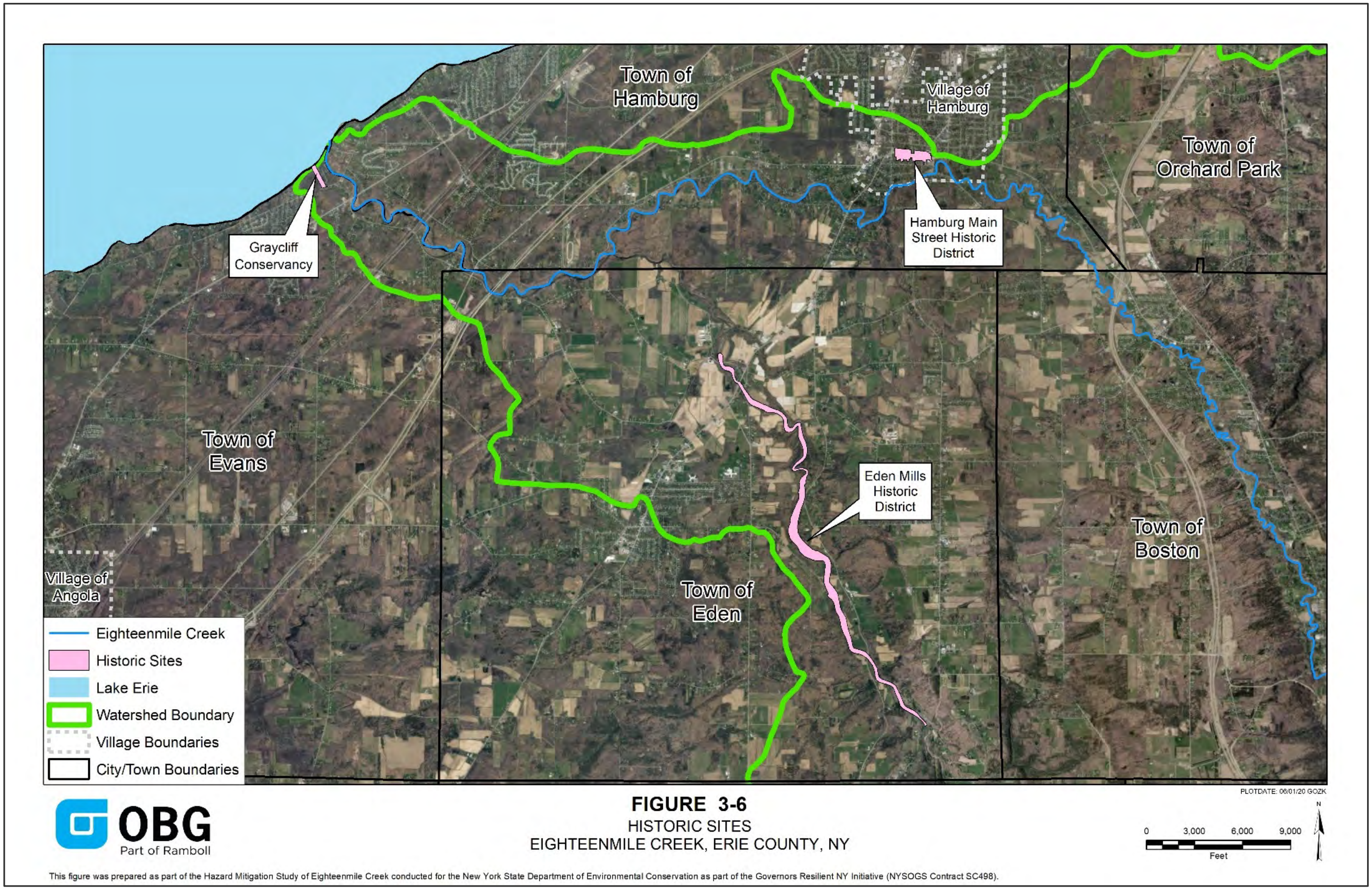

Figure 3-6. National Register of Historic Places, Eighteenmile Creek, Erie County, NY.

3.2.5 FEMA Mapping and Flood Zones

The FEMA Flood Map Service Center (MSC) (https://msc.fema.gov/portal/home) is a database that contains FEMA Flood Insurance Rate Maps (FIRMs) for areas that have had FEMA flood insurance studies completed throughout the United States. For the Towns of Hamburg and Boston, the current effective FEMA FIS was completed on June 7, 2019. The hydrologic and hydraulic analyses completed for the Town of Hamburg was a new detailed study from the original 1980 FIS and for the Town of Boston was a redelineation from the original 1981 FIS. Both H&H analyses included Eighteenmile Creek in their respective FEMA FIS reports (FEMA 2019a; FEMA 2019b; FEMA 2020).

Redelineation is the method of updating effective flood hazard boundaries to match updated topographic data based on the computed water surface elevations from effective models. The results of a redelineation update are more accurate floodplain boundaries when compared to current ground conditions. Redelineation of floodplain boundaries can be applied to both riverine and coastal studies. No new engineering analyses are performed as part of the redelineation methodology; however, redelineation can be paired with new engineering studies as part of a larger update. For riverine studies, effective flood profiles and data tables from the Flood Insurance Study (FIS) report, Base Flood Elevations (BFEs) from the Flood Insurance Rate Maps (FIRMs), and supporting hydrologic and hydraulic analyses are used in conjunction with the updated topographic data to formulate new floodplain boundaries. The coastal redelineation method also typically involves no new analyses. This method combines effective information from the FIRM and FIS Report and the supporting analyses with new, more detailed, or more up to-date topographic data to redelineate coastal high hazard areas (FEMA 2015a). Eighteenmile Creek within the Town of Boston was a redelineation study completed for the effective 2019 FEMA FIS.

For a new detailed study, FEMA can perform a limited detailed or detailed study. For both methods, semiautomated hydrologic, hydraulic, and mapping tools, coupled with digital elevation data, are used to predict floodplain limits, especially in lower-risk areas. If the tools are used with some data collected in the field (e.g. sketches of bridges to determine the clear opening) then the study is considered a limited detailed study. Limited detailed analysis sometimes results in the publishing of the BFEs on the maps. The decision to place BFEs on a limited detailed study analysis is based on the desire of the community for the BFEs to be shown, plus the accuracy of the elevation data and the data on bridges, dams, and culverts that may impede flow on the flooding source. A study performed using these same tools and the same underlying map, with the addition of field-surveyed cross sections, field surveys of bridges, culverts, and dams, along with a more rigorous analysis including products such as floodways, new calibrations for hydrologic and hydraulic models, and the modeling of additional frequencies, is a detailed study. Detailed studies provide BFE information and flood profiles and usually a floodway, whereas approximate studies do not (NRC 2007). Eighteenmile Creek within the Town of Hamburg was a new detailed study completed for the effective 2019 FEMA FIS.

The FIRM for the Eighteenmile Creek indicates Special Flood Hazard Areas (SFHAs), which are land areas covered by floodwaters during the 1% annual chance flood event

(ACE), along the banks of the creek, for almost the entire length of the creek (FEMA 2019a). Eighteenmile Creek is a Regulatory Floodway, which is defined the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than 1-foot over the 1% annual chance flood hazard water surface elevation, referred to as the Base Flood Elevation (BFE). In the regulatory floodway, communities must regulate encroachments, including fill, new construction, substantial improvements, and other development within the adopted regulatory floodway and demonstrate through hydrologic and hydraulic analyses performed in accordance with standard engineering practice that the proposed encroachment would not increase flood levels within the community during the occurrence of the base flood discharge. The floodway is the area that needs to be kept free of encroachment in order to convey the base flood. Development in the portions of the floodplain beyond the floodway, referred to as the floodway fringe, is allowed as long as it does not increase the BFE more than 1.0 ft. (FEMA 2000).

For streams and other watercourses where FEMA has provided BFEs, but no floodway has been designated, or where FEMA has not provided BFEs, the community must review floodplain development on a case-by-case basis to ensure that increases in water surface elevations do not occur or identify the need to adopt a floodway if adequate information is available. The flood zones indicated in the Eighteenmile Creek study area are Zones A, AE and AO, where mandatory flood insurance purchase requirements apply within these areas. A Zones are areas subject to inundation by the 1-percent annual chance flood event (ACE) generally determined using approximate methodologies. Because detailed hydraulic analyses have not been performed, no BFEs or flood depths are shown. AE Zones are areas that have a 1-percent annual chance of flooding where BFEs are provided by FEMA. AO zones are shallow flooding areas where FEMA provides a base flood depth, which indicates the depth of water above highest adjacent grade resulting from a flood that has a 1-percent annual chance of equaling or exceeding that level. FEMA does not provide a BFE for Zone AO's (FEMA 2000). Figure 3-7 is a FIRM that includes a portion of Eighteenmile Creek in the Towns of Hamburg and Boston, NY. (FEMA 2019b).

With regards to ice jam flooding, the effective FEMA FIRMs only reflect flooding related to open water or free flow conditions. For this study, ice jam flooding extents were determined using a wide variety of sources, including stakeholder input, news reports, computer models, etc. References to ice jam flood extents are based solely on these sources and do not reflect the flood zone areas from the effective FEMA FIRMs.

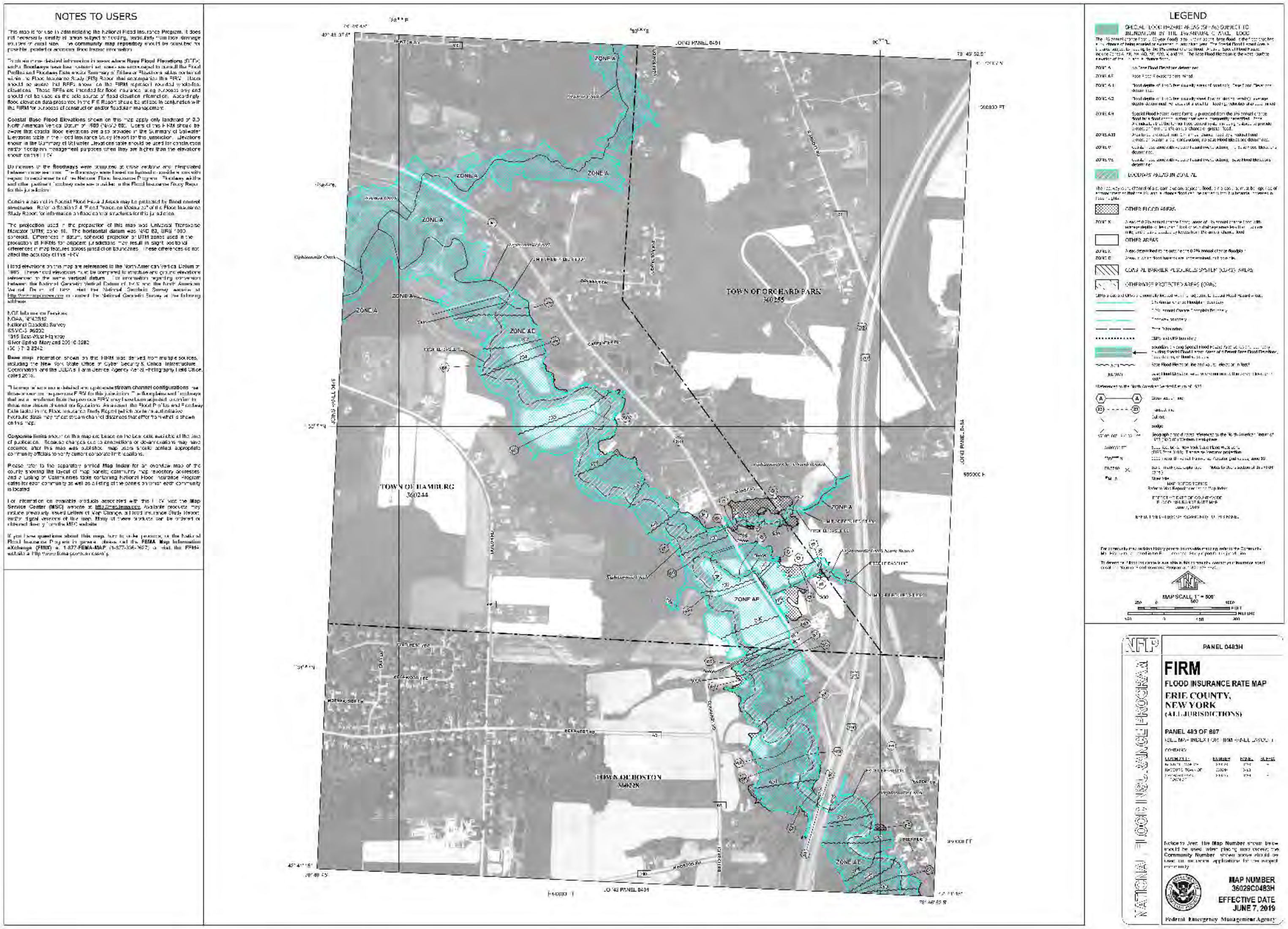

Figure 3-7. FEMA FIRM, Eighteenmile Creek, Hamburg and Boston, Erie County, NY.

3.3 WATERSHED LAND USE

The Eighteenmile Creek stream corridor is largely comprised of forested (56%) and cultivated lands (23%) within the basin. Of the forested lands, deciduous forests (48%) comprise the largest proportion of forest type, while other hay/non alfalfa (13%) and corn (7%) encompasses the largest percentages of cultivated land. Developed lands, including high, medium, and low intensity development and open developed space, comprise a small proportion (9%) of total land use within the Eighteenmile Creek basin (NASS 2019).

In the Town of Boston, there is very little floodplain development, with farmland and wooded areas most prevalent (FIA 1981). Similarly, in the Town of Hamburg, floodplain areas are also primarily undeveloped with most of the land adjacent to Eighteenmile Creek being lined with trees and brush and residential units scattered throughout (FEMA 2001). However, within the Village of Hamburg, the majority of the village has been developed with many residential and commercial buildings and infrastructure (FEMA 1981).

3.4 GEOMORPHOLOGY

In the Towns of Boston and Concord, drainage along the Eighteenmile Creek valley follows the major bedrock joints where the northern two-thirds of the valley is a glacially carved, U-shaped trough, with a floor wide enough to allow broad meanders of the creek channel (FHA 1978).

The bedrock geology of the Eighteenmile Creek basin is primarily made up of the Java & West Falls Group in the Town of Hamburg, and the Canadaway Group in the Town of Boston. The Java & West Falls group consists of extensive sandstone and shale formations and extend southward into the valleys at the northern edge of the Allegheny Plateau. The Canadaway Group consists of shales, sandstones, and siltstones. This group is the youngest geologic feature in Erie County and encompasses the southern portion of the County. The bedrock under the county is fairly flat but dips or tilts approximately 50 feet per mile to the southwest. The rocks have retained much of the form they had when they were deposited as silts and sands in the ancient seas that covered this area approximately 300-million years ago (USSCS 1986; Dicken et al. 2008).

Prehistoric advances and retreats of glacial ice during the last ice age, beginning approximately 300,000 years ago and ending 10,000 years ago, affected the bedrock and soil composition of Erie County, NY. Soil material and pieces of bedrock would be carried and redeposited by moving glacial sheets creating unconsolidated materials of various sizes, shapes, and mineral content. Because the deposited materials were variable, different soils formed in them. Erosion and sedimentation have been at work since the ice retreated and, as a result, steep, fan- shaped alluvial deposits accumulated at the mouths of streams where the velocity of the water slowed, and the sand and gravel dropped out of suspension (USSCS 1986).

Within the Eighteenmile Creek watershed basin, the most predominant soil types are Mardin channery silt loam (MdB), Orpark silty clay loam (OrB), and Volusia channery silt loam (VpB) (NRCS 2019). MdB makes up the largest proportion of soil type by total acreage (6%) with the Eighteenmile Creek basin and consists of sloping soil that is deep and moderately well drained since it formed in loamy glacial till. This soil is on broad convex divides, on ridges and knolls, and on undulating areas of upland till plains. OrB comprises the second largest proportion of soil type (5%) in the basin, and this gently sloping soil is moderately deep and somewhat poorly drained. It formed in acid glacial till deposits underlain by soft shale bedrock. This soil is on side slopes adjacent to nearly flat benches, and on ridge crests of the shelf-like northern edge of the upland plateau and commonly receives runoff from higher adjacent soils. VpB is the third largest proportion of soil type (4%) and is also a gently sloping soil that is deep and somewhat poorly drained. It formed in acid glacial till deposits. This soil is on foot slopes and other areas of the upland plateau that commonly receive seepage or runoff from higher adjacent soils (USSCS 1986).

Figure 3-8 is a profile of stream bed elevation and channel distance from the confluence with Lake Erie using 1-meter light detection and ranging (LiDAR) data for Eighteenmile Creek. Eighteenmile Creek has an average slope of 0.6% over the profile stream length. The creek's streambed lowers approximately 1,000 vertical feet over this reach from an elevation of 1,580-feet above sea level (NAVD 88) at the headwaters in the Town of Concord, to 572-feet above sea level at the confluence of Lake Erie in the Town of Hamburg, NY (NYSDEC 2008).

The slope of Eighteenmile Creek is not uniform throughout its flow path. The upstream portion of the creek, from the headwaters to the Boston-Colden Town boundary, has an average slope of 1.8%, while the middle reach through the Town of Boston and the lower reach through the Town of Hamburg to the confluence with Lake Erie have an average slope of 0.3%. The difference in slope contributes to channel bank erosion in the upstream and concentrates runoff and sediment deposition in the middle and lower reaches of Eighteenmile Creek (NYSDEC 2008).

In addition, there are numerous locations where sediment depositional aggradation is occurring within the channel of Eighteenmile Creek. Aggradation is a fluvial process where sediment and other materials are deposited in a stream channel when the supply of sediment is greater than the amount of material that the system is able to transport. Over time, aggradation can lead to the development of sand and sediment bars within the stream channel. These sand and sediment bars restrict flow by reducing the in-channel flow area and act as catchpoints for ice pieces during ice breakup events, potentially increasing open water flood risks and ice jam formations (Mugade and Sapkale 2015).

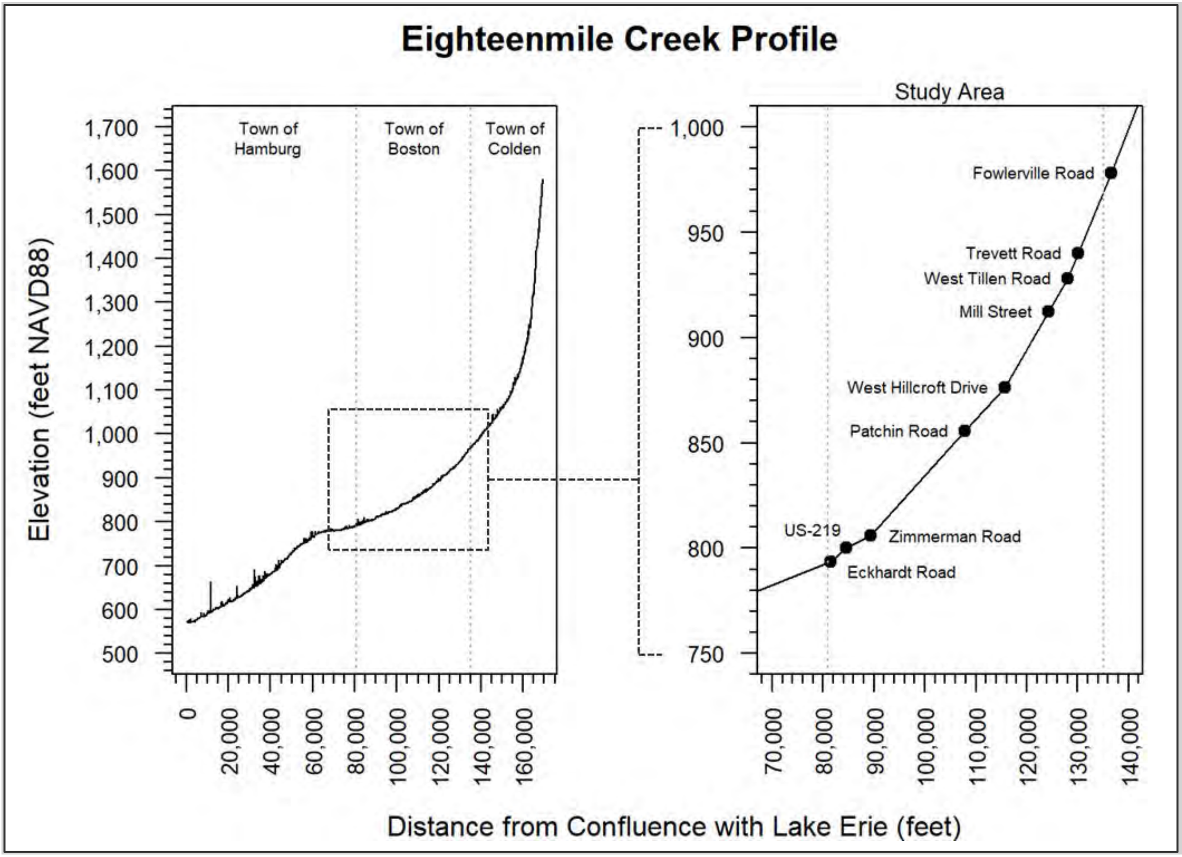

Figure 3-8. Eighteenmile Creek profile of stream bed elevation and channel distance from the confluence with Lake Erie.

3.5 HYDROLOGY

Eighteenmile Creek is approximately 32-miles long and drains an area of 120 square miles. The creek channel has cut deep valleys in the upper and middle reaches of the watershed from the headwaters in the Town of Concord down to the Village of Hamburg. As a result, the upper and middle reaches have a narrow floodplain with high valley slopes on both sides of the creek. The valley includes over 50 tributaries which drain the east and west slopes within the towns, and as the creek enters North Boston, the valley and floodplain widen and become relatively flat with a mild average slope of 0.5-ft per 100-ft (FHA 1978; FIA 1981).

Table 2 is a summary of the basin characteristic formulas and calculated values for the Eighteenmile Creek watershed, where A is the drainage area of the basin in square miles, B_L is the basin length in miles, and B_P is the basin perimeter in miles (USGS 1978).

Table 2. Eighteenmile Creek Basin Characteristics Factors

Factor	Formula	Value
Form Factor (R_F)	A / B_L^2	0.30
Circularity Ratio (R_C)	$4*\pi*A / B_P^2$	0.39
Elongation Ratio (R_E)	$2 * (A/\pi)^{0.5} / B_L$	0.62

Form Factor (R_F) describes the shape of the basin (e.g., circular or elongated) and the intensity of peak discharges over a given duration of time. Circularity Ratio (R_C) gives an indication of topography where the higher the circularity ratio, the lower the relief and less disturbance to drainage systems by structures within the channel. Elongation Ratio (R_E) gives an indication of ground slope where values less than 0.7 correlate to steeper ground slopes and elongated basin shapes. Based on the basin characteristics factors, the Eighteenmile Creek watershed can be characterized as an elongated basin with lower peak discharges of longer durations, high-relief topography with structural controls on drainage, and steep ground slopes (Waikar and Nilawar 2014).

There are two USGS stream gaging stations on Eighteenmile Creek in Erie County, USGS gage 04214200 at North Boston, NY and USGS gage 042142210 at Hamburg, NY; however, the longest period of record for the gaging stations is less than 15 years, which is insufficient for hydrologic analysis. An effective FEMA FIS for Erie County was issued on June 7, 2019 and included drainage area and discharge information for Eighteenmile Creek. Table 3 lists the FEMA FIS drainage area and peak discharges, in cubic feet per second, for Eighteenmile Creek (FEMA 2019b).

Table 3. Eighteenmile Creek FEMA FIS Peak Discharges

(Source: FEMA 2019b)						
			Peak Discharges (cfs)			
Flooding Source and Location	**Drainage Area (Sq. Miles)**	**River Station (ft)**	**10-Percent**	**2-Percent**	**1-Percent**	**0.2-Percent**
At confluence with Lake Erie	120	0+00	11,000	15,000	16,500	20,000
Upstream of confluence of Eighteenmile Creek South Branch	64.8	297+00	4,920	6,990	7,960	10,300
Upstream of Creek Road	62.3	448+00	4,740	6,720	7,660	9,950
At town of Boston / Town of Hamburg corporate limits	39	779+00	4,640	5,880	6,380	7,430
Upstream of USGS gaging station in Town of Boston	36.9	868+00	4,430	5,620	6,100	7,100
Upstream of confluence of Irish Gulf	31.1	966+00	3,730	4,730	5,130	5,970
Upstream of confluence of Anthony Gulf	27.4	1042+50	3,290	4,170	4,530	5,270
Upstream of Pfarner Road	21.4	1207+00	2,590	3,280	3,560	4,140
Upstream of confluence with Landon Brook	14.1	1295+00	1,720	2,190	2,370	2,760

According to the effective FEMA FIS, for Eighteenmile Creek in the Town of Boston, peak discharges were determined by USGS using a log-Pearson Type III analysis (USGS, unpublished) to correlate stream flow with storm events. In the Town of Hamburg, peak discharges were determined using drainage area proportioning and a coefficient determined by McPhee, Smith, Rosenstein Engineers (Johnstone and Cross 1949). Water surface profiles in the towns of Evans and Hamburg were computed through the use of three different methods. For reaches, including bridges, exhibiting subcritical (tranquil) flow, the USGS E431 step-backwater program was used. At cross-sections where flow was supercritical (rapid), water-surface elevations were computed using critical depth computations. Finally, where the profile through bridges and culverts passed through critical depth, the USGS A526 culvert computer program was used to determine water-surface elevations upstream from the structure (USGS 1976). When warranted, flow over roads at these bridges and culverts were computed manually. Starting water-surface elevations were based on known elevations of Lake Erie at the confluence. In the Town of Boston, water-surface profiles were computed using HEC-2. Starting water-surface elevations were obtained from the profiles for Eighteenmile Creek in the Town of Hamburg FIS (USACE 1973; FEMA 2019b).

Within the Town of Hamburg, FEMA performed a new detailed study for Eighteenmile Creek. Cross sections were obtained from contour data developed from LiDAR data. Below-water cross sections were obtained by field surveys. All bridges, dams and miscellaneous structures were field surveyed to obtain elevation data and structural geometry. As-build drawings provided by USACE and NYSDOT were utilized to supplement survey data where needed. Water-surface elevations for the floods of selected recurrence intervals were computed through the use of HEC-RAS (version 3.1.3 and 4.0) step-backwater computer program. The channel and overbank roughness values were assigned in HEC-RAS based on the information obtained from survey, aerial imagery, site inspection and engineering judgment. These computations were checked by field observation of the streams and floodplain areas at selected cross sections. The roughness factors were estimated at each cross section using the Soil Conservation Service (SCS) procedure. Starting water surface elevations were established using normal depth computations in HEC-RAS (FEMA 2019b).

General limitations of the FEMA FIS methodology are the multiple water surface elevation calculation methods used, including manual calculations, which can introduce a large degree of uncertainty and errors into the calculations and the limited sample size of discharge data available from the USGS stream gages, which did not exceed 15 years of data, and were used to extrapolate or perform a log-Pearson III (LP3) regression analysis for stream flows at the annual chance flood hazard events (i.e. 10, 2, 1, and 0.2-percent).

StreamStats v4.3.11 software (https://streamstats.usgs.gov/ss/) is a map-based web application that provides an assortment of analytical tools that are useful for water-resources planning and management, and engineering purposes. Developed by the USGS, the primary purpose of *StreamStats* is to provide estimates of streamflow statistics for user selected ungaged sites on streams and for USGS stream gages, which are locations where streamflow data are collected (Ries et al. 2017; USGS 2017).

Methods for computing a peak discharge estimate for a selected recurrence interval at a specific site depend on whether the site is gaged or ungaged, and whether the drainage area lies within a single hydrologic region or crosses into an adjacent hydrologic region or State. Hydrologic regions refer to areas in which streamflow-gaging stations indicate a similarity of peak-discharge response that differs from the peak-discharge response in adjacent regions. These similarities and differences are defined by the regression residuals, which are the differences between the peak discharges calculated from station records and the values computed through the regression equation. There are currently six hydrologic regions in New York State (Lumia 1991; Lumia et al. 2006).

For gaged sites, such as Eighteenmile Creek in hydrologic region 5 of New York State, the generalized least-squares (GLS) regional-regression equations are used to improve streamflow-gaging-station estimates (based on log-Pearson type III flood-frequency analysis of the gaged annual peak-discharge record) by using a weighted average of the two estimates (regression and gaged). Incorporating the regression estimate into the weighted average tends to decrease time sampling errors that result for sites with short periods of record. The weighted-average discharges are generally the most reliable and are computed from the equation:

$$Q_{T(W)} = Q_{T(g)}(N) + Q_{T(r)}(E) / N + E$$

where

$Q_{T(w)}$ is weighted peak discharge at the gaged site, in cubic feet per second, for the T-year recurrence interval;

$Q_{T(g)}$ is peak discharge at gage, in cubic feet per second, calculated through log-Pearson Type III frequency analysis of the station’s peak discharge record, for the T-year recurrence interval;

N is number of years of annual peak-discharge record used to calculate $Q_{T(g)}$ at the gaging station;

$Q_{T(r)}$ is regional regression estimate of the peak discharge at the gaged site, in cubic feet per second, for the T-year recurrence interval; and

E is average equivalent years of record associated with the regression equation that was used to calculate $Q_{T(r)}$ (Lumia et al. 2006).

StreamStats delineates the drainage basin boundary for a selected site by use of an evenly spaced grid of land-surface elevations, known as a Digital Elevation Model (DEM), and a digital representation of the stream network. Using this data, the application calculates multiple basin characteristics, including drainage area, main channel slope, and mean annual precipitation. By using these characteristics in the calculation, the peak discharge values have increased accuracy and decreased standard errors by approximately 10% for a 1-percent annual chance interval (100-year recurrence) discharge when compared to the drainage-area only regression equation (Lumia et al. 2006; Ries et al. 2017).

When *StreamStats* is used to obtain estimates of streamflow statistics for USGS stream gages, users should be aware that there are errors associated with estimates determined from available data for the stations as well as estimates determined from regression equations, and some disagreement between the two sets of estimates is expected. If the flows at the stations are affected by human activities, then users should not assume that the differences between the data-based estimates and the regression equation estimates are equivalent to the effects of human activities on streamflow at the stations (Ries et al. 2017).

StreamStats was used to calculate the current peak discharges for Eighteenmile Creek and compared with the effective FIS peak discharges. Table 4 is the summary output of peak discharges calculated by the USGS StreamStats software for Eighteenmile Creek at the same locations as the FEMA FIS peak discharges.

Table 4. USGS *StreamStats* Peak Discharge for Eighteenmile Creek at the FEMA FIS Locations

(Source: USGS 2017)						
			Peak Discharges (cfs)			
Flooding Source and Location	Drainage Area (Sq. Miles)	River Station (ft)	10-Percent	2-Percent	1-Percent	0.2-Percent
At confluence with Lake Erie	121	0+00	6,890	10,200	11,700	15,500
Upstream of confluence of Eighteenmile Creek South Branch	66.4	297+00	3,940	5,810	6,640	8,730
Upstream of Creek Road	62.6	448+00	3,790	5,590	6,390	8,410
At town of Boston / Town of Hamburg corporate limits	39.1	779+00	3,070	4,620	5,320	7,090
Upstream of USGS gaging station in Town of Boston	37.1	868+00	3,140	4,760	5,490	7,370
Upstream of confluence of Irish Gulf	31.2	966+00	2,880	4,390	5,080	6,850
Upstream of confluence of Anthony Gulf	27.4	1042+50	2,720	4,170	4,840	6,550
Upstream of Pfarner Road	21.3	1207+00	2,610	4,090	4,780	6,570
Upstream of confluence with Landon Brook	14.1	1295+00	2,050	3,280	3,850	5,360

Using the standard error calculations from the regression equation analysis in *StreamStats*, an acceptable range at the 95% confidence interval for peak discharge values at the 10, 2, 1, and 0.2-percent annual chance flood hazards were determined.

Standard error gives an indication of how accurate the calculated peak discharges are when compared to the actual peak discharges since approximately two-thirds (68.3-percent) of the calculated peak discharges would be within one standard error of the actual peak discharge, 95.4-percent would be within two standard errors, and almost all (99.7-percent) would be within three standard errors (McDonald 2014). Table 5 is a summary table of the USGS *StreamStats* standard errors at each percent annual chance flood hazard. Based on the *StreamStats* standard error calculations, the FEMA FIS peak discharges were determined to be outside of the acceptable range (95% confidence interval).

Table 5. USGS *StreamStats* standard errors for full regression equations

Source: (Lumia 2006)				
	Peak Discharges (cfs)			
	10-Percent	**2-Percent**	**1- Percent**	**0.2- Percent**
Standard Error	36.1	37.5	38.7	42.6

For this study, the USGS *StreamStats* peak discharges were used in the HEC-RAS model simulations due to the fact that the *StreamStats* program offers a more robust and modern methodology, a more conservative analysis of flood risk in the Eighteenmile Creek watershed, and is not affected by the general limitations of the FEMA FIS discharge methodology (e.g. multiple different calculation methods and insufficient peak discharge data sample size for LP3).

In addition to peak discharges, the *StreamStats* software also calculates bankfull statistics by using stream survey data and discharge records from 281 cross-sections at 82 streamflow-gaging stations in a linear regression analyses to relate drainage area to bankfull discharge and bankfull-channel width, depth, and cross-sectional area for streams across New York state. These equations are intended to serve as a guide for streams in areas of the same hydrologic region, which contain similar hydrologic, climatic, and physiographic conditions (Mulvihill et al. 2009).

Bankfull discharge is defined as the flow that reaches the transition between the channel and its flood plain. Bankfull discharge is considered to be the most effective flow for moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphological characteristics of channels (Mulvihill et al. 2009). The bankfull width and depth of Eighteenmile Creek is important in understanding the distribution of available energy within the stream channel and the ability of various discharges occurring within the channel to erode, deposit, and move sediment (Rosgen and Silvey 1996). Table 6 lists the estimated bankfull discharge, width, and depth at select locations along Eighteenmile Creek as derived from the USGS *StreamStats* program.

Table 6. USGS *StreamStats* Estimated Bankfull Discharge, Width, and Depth

(Source: USGS 2017)				
Flooding Source and Location	**River Station (ft)**	**Bankfull Depth (ft)**	**Bankfull Width (ft)**	**Bankfull Streamflow (cfs)**
At confluence with Lake Erie	0+00	3.35	126	2,720
Upstream of confluence of Eighteenmile Creek South Branch	297+00	2.89	98	1,640
Upstream of Creek Road	448+00	2.85	96	1,560
At town of Boston / Town of Hamburg corporate limits	779+00	2.54	79	1,050
Upstream of USGS gaging station in Town of Boston	868+00	2.51	77	1,010
Upstream of confluence of Irish Gulf	966+00	2.41	71	870
Upstream of confluence of Anthony Gulf	1042+50	2.33	68	780
Upstream of Pfarner Road	1207+00	2.19	61	631
Upstream of confluence with Landon Brook	1295+00	1.98	51	446

3.6 INFRASTRUCTURE

There are numerous dams along Eighteenmile Creek and its tributaries that interact with the flow of the creek. Of the five dams along Eighteenmile Creek, three are purposed as irrigation dams, while one is a recreation dam, and the other dam is hydroelectric. All dams along the creek are classified as a Class D or 0 dam. Class D dams are also referred to as “negligible or no hazard” dams, which are defined as dams that have been breached or removed, or have failed or otherwise no longer materially impound waters, or dams that were planned but never constructed and are considered to be defunct dams posing negligible or no hazard. Class 0 dams are defined as dams that have not had a hazard code assigned. Table 7 lists the dams that are along Eighteenmile Creek, including hazard codes and purpose for the dam (NYSDEC 2019b).

Table 7. Inventory of Dams along Eighteenmile Creek

(Source: NYSDEC 2019b)					
Municipality	**Owner**	**Dam Name**	**River Station (ft)**	**Hazard Code**	**Purpose**
Town of Hamburg	Private	Paragon Mill Dam	520+00	D	Irrigation
Village of Hamburg	Private	Schoepflin Mill Dam	610+00	D	Irrigation
Town of Hamburg	Village of Hamburg	Hamburg North Branch Dam	635+00	0	Irrigation
Town of Boston	Private	Brunnen Mill Dam	1210+00	D	Hydroelectric
Town of Concord	Private	Samuel Darlich Pond Dam	1479+00	D	Recreation

Major bridge crossings over Eighteenmile Creek include Interstate 90, Southern Expressway (US-219), Lake Shore Road (NY-5), Southwestern Blvd (US-20), and Gowanda State Road (US-62) in the Town of Hamburg. Bridge lengths and surface widths for NYSDOT bridges were revised as of February 2019. Table 8 summarizes the infrastructure data for bridges that cross Eighteenmile Creek that are within the study area with bankfull widths from the USGS *StreamStats* program. Figure 3-9 displays the locations of the bridges and dams that cross Eighteenmile Creek in Erie County, NY (NYSDOT 2016b; USGS 2017).

Table 8. Infrastructure Crossing Eighteenmile Creek within the Study Area

(Source: NYSDOT 2016b)							
Roadway Carried	**Primary Owner**	**River Station (ft)**	**NYSDOT BIN**	**Bridge Length (ft)**	**Surface Width[1] (ft)**	**Bankfull Width (ft)**	**Hydraulic Capacity (% Annual Chance)**
Old Lakeshore Road	Erie County	24+00	3327790	182	28	125	0.2
Lake Shore Road / NY-5	NYSDOT	40+50	1001380	479	57.5	125	0.2
Southwestern Blvd / US-20	NYSDOT	182+00	1015450	416	56	124	No FEMA FIS Data
Interstate 90 (Westbound)	NYS Thruway Authority	201+00	5512411	636	49.2	123	No FEMA FIS Data
Interstate 90 (Eastbound)	NYS Thruway Authority	202+00	5512412	658	49	123	No FEMA FIS Data
South Creek Road	Town of Hamburg	448+00	2213240	186	24	95.6	0.2
Gowanda State Road / US-62	NYSDOT	520+00	1028210	132	44.3	94.9	0.2
South Buffalo Road	Erie County	615+00	3327590	149	28	88.3	No FEMA FIS Data
Eckhardt Road	Erie County	780+00	3327750	82	29.9	78.5	Less than 10
Southern Expressway / US-219 (Southbound)	NYSDOT	849+00	1071031	138	45.5	78	No FEMA FIS Data

(Source: NYSDOT 2016b)							
Roadway Carried	**Primary Owner**	**River Station (ft)**	**NYSDOT BIN**	**Bridge Length (ft)**	**Surface Width[1] (ft)**	**Bankfull Width (ft)**	**Hydraulic Capacity (% Annual Chance)**
Southern Expressway / US-219 (Northbound)	NYSDOT	850+00	1071032	147	41	78	No FEMA FIS Data
Zimmerman Road	Erie County	867+50	3327600	78	38.9	76.8	2
Patchin Road	Town of Boston	1080+00	3327610	77	28	67.7	No FEMA FIS Data
Hillcroft Drive	Town of Boston	1121+00	3327840	68	24	64.6	0.2
Mill Street	Erie County	1206+00	3327540	70	24	61	0.2
West Tillen Road	Erie County	1245+00	3368440	123	34	58.8	No FEMA FIS Data
Trevett Road	Erie County	1263+00	3328560	72	24	57.3	0.2
Fowlerville Road	Erie County	1365+00	3328630	57	28	50.1	No FEMA FIS Data
Springville Boston Rd	Erie County	1471+00	1041610	38	32.2	40.3	No FEMA FIS Data
Springville Boston Rd	Erie County	1540+00	1041600	38	0	27.4	No FEMA FIS Data

[1] Surface Width is measured parallel to creek flow and refers to the curb-to-curb width, which is the minimum distance between the curbs or the bridge railings (if there are no curbs), to the nearest 30mm or tenth of a foot (NYSDOT 2006).

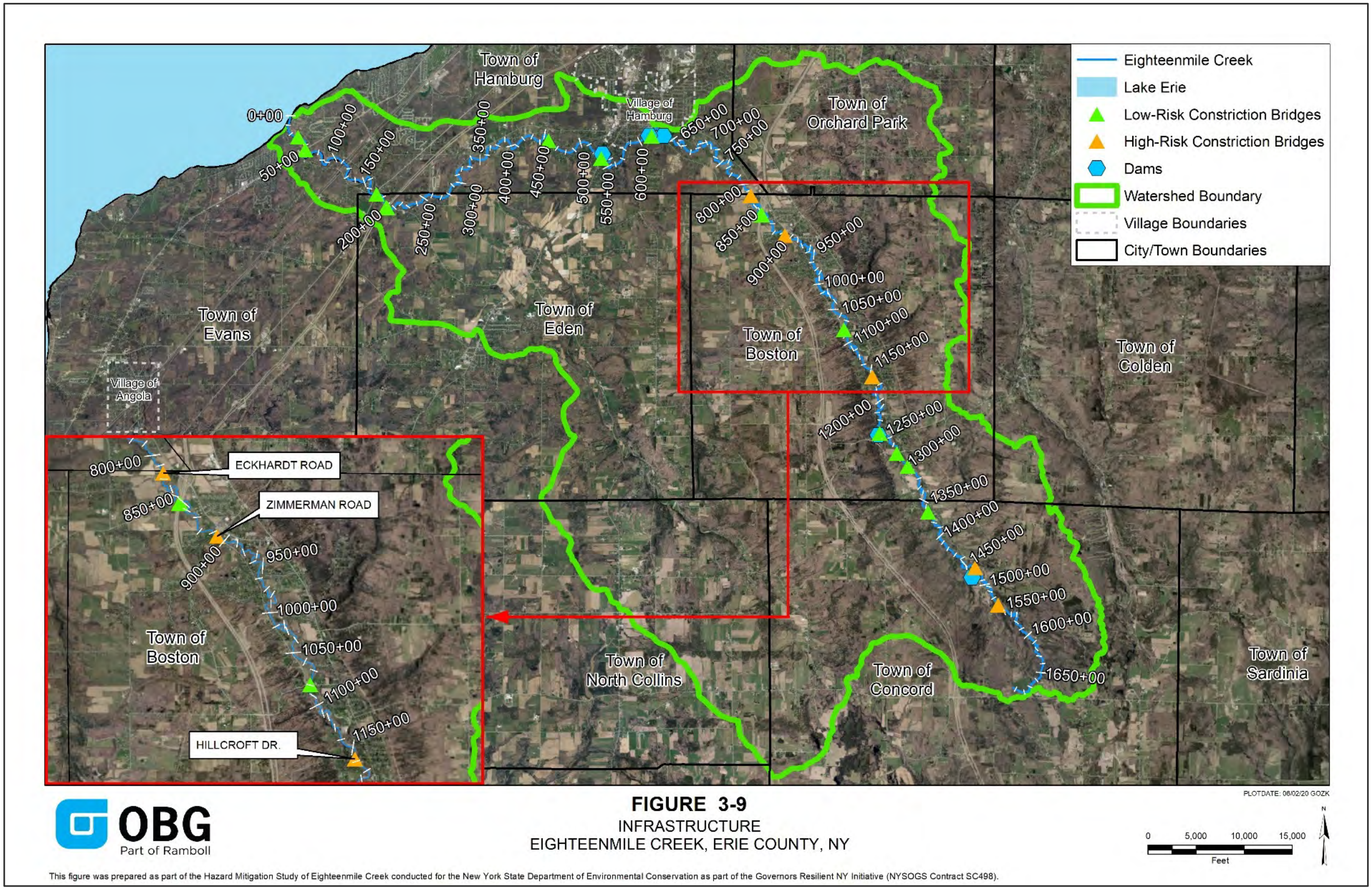

Figure 3-9. Eighteenmile Creek Infrastructure, Erie County, NY.

In addition to the infrastructure in Table 8, Eighteenmile Creek is crossed by: three different railroad bridges owned by CSX Transportation, Norfolk Southern Railway Company, and the Erie County Industrial Development Agency (operated by Buffalo Southern Railroad); Versailles Road, which is owned by the Town of Evans: and, a pedestrian bridge in the 18 Mile Golf Course in the Town of Hamburg. These structures were not within the study area so no hydrologic or hydraulic analyses were performed on these structures.

3.7 HYDRAULIC CAPACITY

Hydraulic capacity is the measure of the amount of water that can pass through a structure or watercourse. Hydraulic design is an essential function of structures in watersheds. Exceeding the capacity can result in damages or flooding to surrounding areas and infrastructure (Zevenbergen et al. 2012). In assessing hydraulic capacity of the high risk constriction point culverts and bridges along Eighteenmile Creek, the FEMA FIS profile of Eighteenmile Creek was used to determine the lowest annual chance flood elevation to flow under the low chord of a bridge or culvert, without causing an appreciable backwater condition upstream (Table 8).

In New York State, hydraulic and hydrologic regulations for bridges were developed by the NYSDOT. The NYSDOT guidelines require a factor of safety for bridges that cross waterways, known as freeboard. Freeboard is the additional capacity, usually expressed as a distance in feet, in a waterway above the calculated capacity required for a specified flood level, usually the base flood elevation. Freeboard compensates for the many unknown factors that could contribute to flood heights being greater than calculated, such as wave action, minor silt and debris deposits, the hydrological effect of urbanization of the watershed, etc. However, freeboard is not intended to compensate for higher floods expected under future climatic conditions, such as those due to sea-level rise or more extreme precipitation events (NYSDEC 2018).

The term “bridge” shall apply to any structure whether single or multiple span construction with a clear span in excess of 20 feet when measurement is made horizontally along the center line of roadway from face to face of abutments or sidewalls immediately below the copings or fillets; or, if there are no copings or fillets, at 6 inches below the bridge seats or immediately under the top slab, in the case of frame structures. In the case of arches, the span shall be measured from spring line to spring line. All measurements shall include the widths of intervening piers or division walls, as well as the width of copings or fillets. (NYSDOT 2020)

According to the NYSDOT bridge manual (2019) for Region 5, which includes Niagara, Erie, Chautauqua, and Cattaraugus Counties, new and replacement bridges are required to meet certain standards, which include (NYSDOT 2019):

- The structure will not raise the water surface elevations anywhere when compared to the existing conditions for both the 2 and 1% ACE (50 and 100 year flood) flows.
- The proposed low chord shall not be lower than the existing low chord.
- A minimum of 2’-0” of freeboard for the projected 2% ACE (50 year flood) is required for the proposed structure. The freeboard shall be measured at the lowest

point of the superstructure between the two edges of the bottom angle for all structures.

- The projected 1% ACE (100 year flood) flow shall pass below the proposed low chord without touching it.
- The maximum skew of the pier to the flow shall not exceed 10 degrees.

In addition, current peak flows shall be increased to account for future projected peak flows based on the USGS *StreamStats* tool where current 2% peak flows shall be increased by 10% in Region 5. For critical bridges, the minimum hydraulic design criteria is 3-feet of freeboard over the 2% annual chance flood elevation. A critical bridge is considered to be vital infrastructure that the incapacity or destruction of such would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters (NYSDOT 2019; USDHS 2010).

Table 9 displays the 2% and 1% annual chance flood levels and their calculated difference at FEMA FIS infrastructure locations using the FIS profile for Eighteenmile Creek.

Table 9. FEMA FIS profile 2 and 1-percent Annual Chance Flood Hazard Levels with Differences at Infrastructure Locations

Source: (FEMA 2019a)				
Bridge Crossing [1]	**River Station (ft)**	**2-Percent Water Surface Elevation (ft NAVD88)**	**1-Percent Water Surface Elevation (ft NAVD88)**	**Difference in Water Surface Elevations (ft NAVD88)**
Old Lakeshore Road	24+00	580	580.5	0.5
Lake Shore Road / NY-5	40+50	586.5	587	0.5
South Creek Road	448+00	718.5	719	0.5
Gowanda State Road / US-62	520+00	756.5	757	0.5
Eckhardt Road	780+00	802	802.25	0.25
Zimmerman Road	867+50	816	816.5	0.5
Patchin Road	1080+00	859.75	860	0.25
Hillcroft Drive	1121+00	885.25	885.5	0.25
Mill Street	1206+00	923	923.5	0.5
West Tillen Road	1245+00	937	937.25	0.25
Trevett Road	1263+00	949.5	950	0.5

[1] The FEMA FIS profiles end at the Boston-Colden corporate limits at river station 1310+00 and does not include structures built after the 1978.

In assessing hydraulic capacity of the high risk constriction point culverts and bridges along Eighteenmile Creek, the FEMA FIS profile of was used to determine the lowest annual chance flood elevation to flow under the low chord of a bridge (Table 8). According to the FEMA FIS profiles, Eckhardt and Zimmerman Road bridges are do not meet the NYSDOT guidelines for freeboard since their low chord elevations are below the 10% annual chance flood event and do not provide the required 2-ft of freeboard (FEMA 2019b). Additionally, these structures do not meet the new draft CRRA climate change infrastructure guidelines as described above. Even though these structures may have hydraulic capacity restraints, the NYSDOT has to balance both physical constraints along with cost versus benefit of replacing existing bridges to meet the new draft CRRA guidelines.

The USGS *StreamStats* tool was used to calculate the bankfull widths and discharge for each structure along Eighteenmile Creek (Table 8). Table 10 is a hydraulic capacity summary for potential constriction point bridges crossing Eighteenmile Creek. Based on the hydraulic capacity analysis, there is one bridge that crosses Eighteenmile Creek where the bridge opening is smaller than the bankfull width: Springville Boston Road bridge in the Town of Concord. In addition, there are several bridges with openings that are very close (within 5 feet) of bankfull width: the Eckhardt Road, Zimmerman Road, and Hillcroft Drive bridges.

Table 10. Hydraulic Capacity of Potential Constriction Point Bridges Crossing Eighteenmile Creek

Source: (NYSDOT 2016b; OBG 2019; USGS 2017; FEMA 2019a)					
Roadway Carried	**River Station (ft)**	**Structure Width (ft)**	**Bankfull Width (ft)**	**Bankfull Discharge (cfs)**	**Annual Chance Flood Event Equivalent[1]**
Eckhardt Road	780+00	82	78.5	1050	80-percent
Zimmerman Road	867+50	78	76.8	1010	80-percent
Hillcroft Drive	1121+00	68	64.6	709	80-percent
Springville Boston Road	1471+00	38	40.3	275	80-percent

[1] Annual Chance Flood Event Equivalent describes the equivalent annual chance flood event for the given bankfull discharge as calculated by the USGS *StreamStats* application. The 80% annual chance flood event is equal to a 1.25-year recurrence interval.

These bridges are an area of concern along Eighteenmile Creek since they are all in the same reach that flows through the Town of Boston, which has historically had issues with erosion and sediment deposition. Since the bankfull widths are wider than or close to the structures width for the Eckhardt, Zimmerman, and Springville Boston Road and Hillcroft Drive bridge crossings, water velocities have to slow and contract in order to pass through the structures. The slowing of water velocities reducing the energy available in the water to transport sediment and debris, which can cause sediment depositional aggradation and the accumulation of sediment and debris over time or during large storm events to occur. Aggradation can lead to the development of sediment and sand bars near meanders or at the upstream opening of bridges, which can cause upstream water surfaces to rise, increasing the potential for overtopping banks or backwater flooding. Since the bankfull discharge required for water surface elevations to reach the bankfull width is low (e.g. 80% ACE), the likelihood of relatively low flow events causing backwater and potential flooding upstream of these structures is fairly high.

4. CLIMATE CHANGE IMPLICATIONS

4.1 FUTURE PROJECTED STREAM FLOW IN EIGHTEENMILE CREEK

In New York state, climate change is expected to exacerbate flooding due to projected increases of 1-8% in total annual precipitation coupled with increases in the frequency, intensity, and duration of extreme precipitation events (events with more than 1, 2, or 4-inches of rainfall) (Rosenzweig, et al., 2011). In response to these projected changes in climate and in an effort to improve flood resiliency of infrastructure in light of future climate change, New York State passed the *Community Risk and Resiliency Act* in 2014. In accordance with the guidelines of the CRRA, the NYSDEC released the *New York State Flood Risk Management Guidance for Implementation of the Community Risk and Resiliency Act* (2018) draft report. In the report, two methods for estimating projected future discharges were discussed: an end of design life multiplier, and the USGS *FutureFlow Explorer* map-based web application (NYSDEC 2018).

In the NYSDEC draft report, recommended flood risk management guidelines for transportation infrastructure were proposed. The NYSDEC draft guidelines recommended increasing peak flows for future conditions by multiplying relevant peak flow parameters, currently used in hydraulic analysis (e.g. 2-percent annual chance or 50-year flood) by a factor specific to the expected service life of the structure and the geographic location of the project, referred to as an end of design life multiplier. For Western New York, the recommended design-flow multiplier is 10-percent for an end of design life of 2025-2100 (NYSDEC 2018).

The USGS *FutureFlow* software is an extension of the *StreamStats* software where regionally specific peak flow regression equations are used to estimate the magnitude of future floods for any stream or river in New York state (excluding Long Island) and the Lake Champlain basin in Vermont. The *FutureFlow* software substitutes a new climate variable (either precipitation or runoff) to the peak flow regression equations. This climate variable is obtained from five climate models that were reviewed by the World Climate Research Programme's (WCRP) Working Group Coupled Modelling (WGCM) team during the 5th Phase of the Coupled Model Intercomparison Project (CMIP5). These five climate models were chosen because they best represent past trends in precipitation for the region (Burns et al. 2015).

With the USGS *FutureFlow* software, climate variable data is evaluated under two future scenarios, termed "Representative Concentration Pathways" (RCP) in CMIP5, that provide estimates of the extent to which greenhouse-gas concentrations in the atmosphere are likely to change through the 21^{st} century. RCP refers to potential future emissions trajectories of greenhouse gases, such as carbon dioxide. Two scenarios, RCP 4.5 and RCP 8.5, were evaluated for each climate model in CMIP5. RCP 4.5 is considered a midrange-emissions scenario, and RCP 8.5 is a high-emissions scenario (Taylor et al. 2011).

Results of the climate models and the RCPs are averaged for three future periods, from 2025 to 2049, 2050 to 2074, and 2075 to 2099. The downscaled climate data for each model and the RCP scenario averaged over these 25-year periods were obtained from the developers of the USGS Climate Change Viewer (https://www.fs.usda.gov/ccrc/

tools/national-climate-change-viewer). The USGS *FutureFlow* software calculates results based on all five climate models for any of the two greenhouse-gas scenarios, and the three time periods. These available results are meant to reflect a range of variations predicted from among the five models, and two greenhouse-gas scenarios (Alder & Hostetler 2017). The predictions of future mean annual runoff, obtained from the USGS *FutureFlow* software were used with the USGS regional regression equations and the computed basin characteristics, described in previous sections, to compute the expected future peak flows. The USGS *FutureFlow* software provides five estimates of the mean annual runoff for each RCP and future time period, one corresponding to each of the five climate models used. Future flows were computed for each of the five models corresponding to RCP 8.5 and the 2075 to 2099 time period, and the mean computed from the five results are displayed. Table 11 is a summary of the USGS *FutureFlow* projected peak discharges at the FEMA FIS locations.

Table 11. Eighteenmile Creek Projected Peak Discharges using USGS *FutureFlow* software

(Source: USGS 2016)						
			Peak Discharges (cfs)			
Flooding Source and Location	**Drainage Area (mi^2)**	**River Station (ft)**	**10-Percent**	**2-Percent**	**1-Percent**	**0.2-Percent**
At confluence with Lake Erie	120	0+00	8,272	11,727	13,254	17,090
Upstream of confluence of Eighteenmile Creek South Branch	64.8	297+00	4,681	6,623	7,476	9,609
Upstream of Creek Road	62.3	448+00	4,490	6,358	7,179	9,233
At town of Boston / Town of Hamburg corporate limits	39	779+00	3,620	5,236	5,957	7,776
Upstream of USGS gaging station in Town of Boston	36.9	868+00	3,641	5,324	6,080	7,994
Upstream of confluence of Irish Gulf	31.1	966+00	3,291	4,861	5,571	7,374
Upstream of confluence of Anthony Gulf	27.4	1042+50	3,121	4,632	5,318	7,064
Upstream of Pfarner Road	21.4	1207+00	2,932	4,473	5,184	7,016
Upstream of confluence with Landon Brook	14.1	1295+00	2,302	3,579	4,175	5,720

The HEC-RAS model simulation results for the future condition model parameters using the future projected discharge values are similar to the base-condition model output with the only difference being future projected water surface elevations are up to 1-foot higher at specific locations, generally upstream of bridges due to backwater, as a result of the increased discharges.

Table 12 provides a comparison of HEC-RAS base condition, using USGS *StreamStats*, and future condition, using USGS *FutureFlow*, water surface elevations at the FEMA FIS discharge locations.

Table 12. HEC-RAS Base and Future Conditions Water Surface Elevation Comparison

(Source: USGS 2016; USGS 2017; USACE 2016a)						
			Water Surface Elevations (ft NAVD88) [1]			
Flooding Source and Location	**Drainage Area (mi^2)**	**River Station (ft)**	**10-Percent**	**2-Percent**	**1-Percent**	**0.2-Percent**
At town of Boston / Town of Hamburg corporate limits	39	779+00	+ 0.2	+ 0.1	+ 0.1	+ 0.1
Upstream of USGS gaging station in Town of Boston	36.9	868+00	+ 0.5	+ 0.5	+ 0.4	+ 0.3
Upstream of confluence of Irish Gulf	31.1	966+00	+ 0.4	+ 0.3	+ 0.3	+ 0.2
Upstream of confluence of Anthony Gulf	27.4	1042+50	+ 0.5	+ 0.5	+ 0.4	+ 0.5
Upstream of Pfarner Road	21.4	1207+00	+ 0.5	+ 0.5	+ 0.5	+ 0.6
Upstream of confluence with Landon Brook	14.1	1295+00	+ 0.3	+ 0.1	+ 0.2	+ 0.2

[1] Positive changes in water surface elevation indicate the future conditions water surface elevation is higher than the base condition.

Table 13 provides a comparison of the current 1-percent annual change peak stream flows calculated using the USGS *StreamStats* software and the mean predicted future discharge calculated using the USGS *FutureFlow* software at each of the discharge locations included in the effective FIS.

Table 13. Comparison of 1-Percent Annual Chance Current and Future Discharges

(Source: USGS 2016; USGS 2017)					
Location	**Drainage Area (mi^2)**	**River Station (ft)**	**Current *StreamStats* Discharge (cfs)**	**Predicted *FutureFlow* Discharge (cfs)**	**Change (%)**
At confluence with Lake Erie	120	0+00	11,700	13,250	13.3
Upstream of confluence of Eighteenmile Creek South Branch	64.8	297+00	6,640	7,480	12.6
Upstream of Creek Road	62.3	448+00	6,390	7,180	12.3
At town of Boston / Town of Hamburg corporate limits	39	779+00	5,320	5,960	12.0
Upstream of USGS gaging station in Town of Boston	36.9	868+00	5,490	6,080	10.7
Upstream of confluence of Irish Gulf	31.1	966+00	5,080	5,570	9.7
Upstream of confluence of Anthony Gulf	27.4	1042+50	4,840	5,320	9.9
Upstream of Pfarner Road	21.4	1207+00	4,780	5,180	8.5
Upstream of confluence with Landon Brook	14.1	1295+00	3,850	4,180	8.4

5. FLOODING CHARACTERISTICS

5.1 FLOODING HISTORY

Flooding along Eighteenmile Creek generally occurs in the summer and winter seasons due to heavy rains by convective systems and ice jams caused by above freezing temperatures allowing ice breakups in waterways. Historically, the Eighteenmile Creek basin has experienced very few flooding events, and of these events, none could be considered significant in terms of damages or extent.

According to the effective FEMA FIS for Erie County, NY, in the Town of Hamburg, the Lake Erie shoreline is the major area of flooding due to wave action and high winds. The waters of Lake Erie affect the streams that flow into it by causing backwater at the confluences of these streams with the lake, including Eighteenmile Creek. In addition, the railroad bridges that cross Eighteenmile Creek near the lake are restrictive and cause backwater and potentially flooding areas that normally would not be at risk of flooding (FEMA 2001; FEMA 2019b). In the Town of Boston, no significant flooding records exist for any creek or stream, including Eighteenmile Creek (FIA 1981; FEMA 2019b).

Recently, there have been three reported flood events in the Eighteenmile Creek basin that have caused minor flood damages to property and infrastructure. On January 11, 2014, a combination of rainfall and warm temperatures resulted in ice jams on several streams and creeks in Erie County, including Eighteenmile Creek near the junction of Mill Street and Back Creek Road in the Town of Boston. Reported damages from the flooding event were in excess of $10,000. On August 11, 2015, severe thunderstorms produced heavy rains with instantaneous rainfall rates of four to six inches an hour being observed. These heavy, intense rains combined with the steepening terrain along the edge of residential properties in the Town of Boston caused significant flash flooding and damages to numerous homes along Boston State Road. Reported damages from the flooding event were in excess of $35,000. On February 4, 2019, rapid temperature warmups with record-high temperatures resulted in near total snowmelt and ice breakup on local streams and rivers in Erie County. Ice-jam flooding occurred in the Town of Boston where Heinrich and Eckhardt Roads were closed due to flooding. Reported damages from the flooding event were in excess of $10,000 for the event (NCEI 2020).

FEMA FIRMs are available for Eighteenmile Creek from FEMA. Figures 5-1 and 5-2 display the floodway and 1- and 0.2% annual chance flood event boundaries for Eighteenmile Creek as determined by FEMA for the Towns of Hamburg and Boston, respectively. The maps indicate that in the Town of Hamburg, flooding generally occurs upstream of the Village in the vicinity of the 18 Mile golf course and confluence with Neuman Creek. In the Town of Boston, flooding typically occurs in the vicinity of the Southern Expressway (US-219), both upstream and downstream, and along Back Creek Road in the vicinity of the hamlet of Patchin (FEMA 2019a). Figures 5-1 and 5-2 should be considered an advisory tool for general hazard awareness, education, and flood plain management and are not official and may not be used for regulatory purposes.

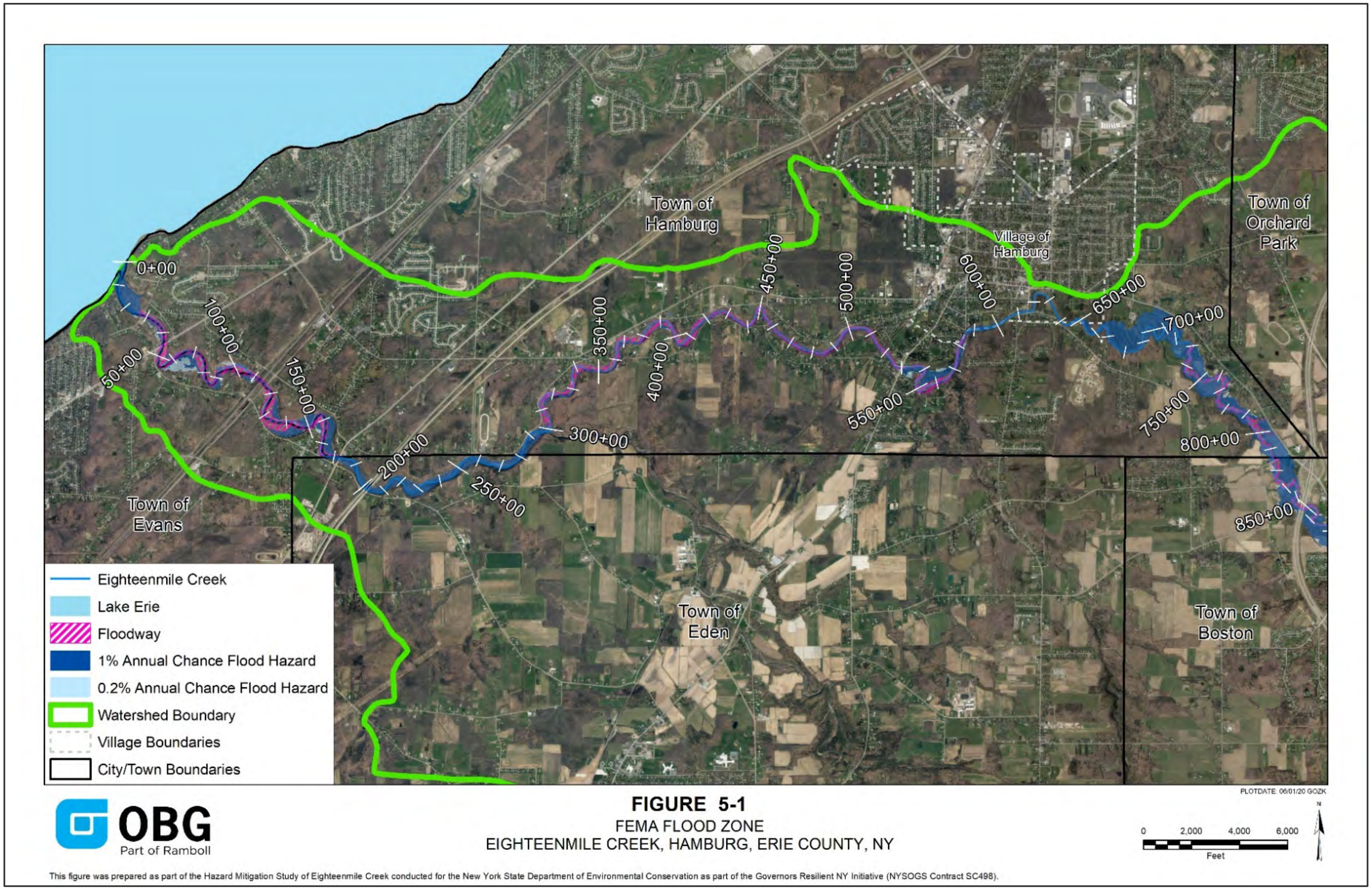

Figure 5-1. Eighteenmile Creek, FEMA flood zones, Hamburg, Erie County, NY.

*Note: This figure is not official and may not be used for regulatory purposes.

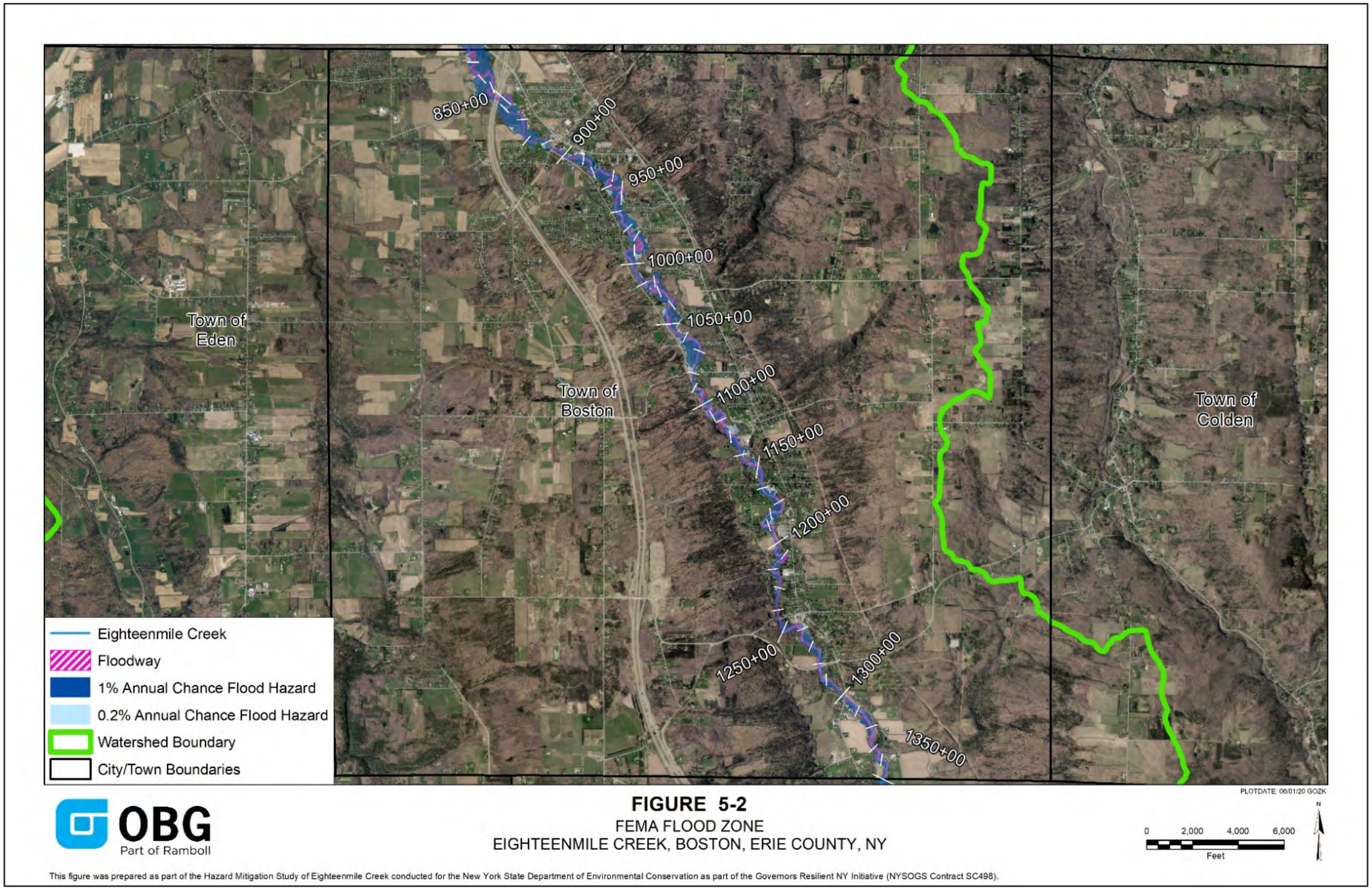

Figure 5-2. Eighteenmile Creek, FEMA flood zones, Boston, Erie County, NY.

*Note: This figure is not official and may not be used for regulatory purposes.

6. FLOOD RISK ASSESSMENT

6.1 FLOOD MITIGATION ANALYSIS

For this study of Eighteenmile Creek, standard hydrologic and hydraulic study methods were used to determine and evaluate flood hazard data. Flood events of a magnitude which are expected to be equaled or exceeded once on the average during any 10, 50, 100, or 500-year period (recurrence interval) have been selected as having special significance for floodplain management and for flood insurance rates. These events, commonly termed the 10, 50, 100, and 500-year floods, have a 10, 2, 1, and 0.2-percent chance, respectively, of being equaled or exceeded during any year. Although the recurrence interval represents the long-term average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year. The risk of experiencing a rare flood increases when periods greater than 1 year are considered. The analyses reported herein reflect flooding potentials based on conditions existing in the county at the time of completion of this study (FEMA 2019b).

Hydraulic analysis of Eighteenmile Creek was conducted using the HEC-RAS v5.0.7 program (USACE 2019). The HEC-RAS computer program was written by the USACE Hydrologic Engineering Center (HEC) and is considered to be the industry standard for riverine flood analysis. The model is used to compute water surface profiles for 1 and 2-Dimensional (2-D), steady-state, or time-varied (unsteady) flow. In 1-Dimensional (1-D) solutions, the water surface profiles are computed from one cross section to the next by solving the one-dimensional St. Venant equation with an iterative procedure (i.e. standard step backwater method). Energy losses are evaluated by friction (Manning's Equation) and the contraction / expansion of flow through the channel. The momentum equation is used in situations where the water surface profile is rapidly varied, such as hydraulic jumps, mixed-flow regime calculations, hydraulics of dams and bridges, and evaluating profiles at a river confluence (USACE 2016a).

Hydraulic and Hydrologic modeling of Eighteenmile Creek in the Town of Boston was completed by FEMA in 1979. Due to the age and format of the 1981 study, an updated 1-D HEC-RAS model was developed using the following data and software:

- Erie County, NY 1-meter LiDAR DEM data (NYSDEC 2008)
- New York State Digital Ortho-imagery Program imagery for Erie County (NYSOITS 2017)
- National Land Cover Database (NLCD) data (USGS 2019)
- USGS *StreamStats* peak discharge data (USGS 2017)
- RAS Mapper extension in the HEC-RAS v5.0.7 software (USACE 2019)
- ESRI ArcMap 10.7 with the HEC-GeoRAS extension GIS software (ESRI 2019)

The hydraulics model was developed for Eighteenmile Creek beginning downstream of South Buffalo Street in the Village of Hamburg (river station 600+00) and extending upstream to the confluence of Eighteenmile Creek with Landon Brook upstream Trevett Road in the Town of Boston (river station 1280+00).

6.1.1 Methodology of HEC-RAS Model Development

Using the LiDAR DEM data, orthoimagery, land cover data, and the RAS Mapper extension in the HEC-RAS software, a base condition model was developed using the following methodology:

- Main channel, bank lines, flow paths, and cross-sections, which were drawn along the main channel at stream meanders, contraction / expansion points, and at structures, were digitized in RAS Mapper
- These features were then exported to the ESRI ArcMap 10.7 GIS software
- Using the HEC-GeoRAS extension in ArcMap 10.7, LiDAR DEM data, and NLCD land cover data, terrain profiles with elevations, cross-section downstream reach lengths, and Manning's n values were assigned to each cross-section
- These features were then imported into HEC-RAS where a 1-D steady flow simulation was performed using USGS *StreamStats* peak discharges

The base condition model water surface elevation results were then compared to the FEMA FIS water surface profiles, past flood events with known water surface elevations, and the effective FEMA FIS elevation profiles to validate the model. After the base condition model was verified, it was then used to develop proposed condition models to simulate potential flood mitigation strategies. The simulation results of the proposed conditions were evaluated based on their reduction in water surface elevations. The flood mitigation strategies that were modeled were:

- Widening of the Eckhardt Road bridge crossing
- Flood benches upstream Eckhardt Road
- Flood benches upstream US-219
- Widening of the Zimmerman Road bridge crossing
- Flood benches upstream Zimmerman Road
- Widening of the Hillcroft Drive bridge crossing
- Flood benches upstream Hillcroft Drive
- Widening of the Mill Street bridge crossing
- Flood bench upstream Mill Street

6.2 COST ESTIMATE ANALYSIS

Rough order of magnitude (ROM) cost estimates were prepared for each mitigation alternative. In order to reflect current construction market conditions, a semi-analogous cost estimating procedure was used by considering costs of a recently completed, similar scope construction project performed in Upstate New York. Phase I of the Sauquoit Creek Channel and Floodplain Restoration Project in Whitestown, NY contained many elements similar to those found in the proposed mitigation alternatives.

Where recent construction cost data was not readily available, RSMeans CostWorks 2019 was used to determine accurate and timely information (RSMeans Data Online 2019). Costs were adjusted for inflation and verified against current market conditions and trends.

For mitigation alternatives where increases in bridge or culvert sizes were recommended, bridge or culvert size increases were initially analyzed based on 2-feet freeboard over the base flood elevation for a 1% annual chance flood event. Once these optimal sizes were determined, further analysis was completed including site constraints and constructability. Due to these additional constraints, for some mitigation measures the size necessary to meet the freeboard requirement was not feasible. Cost estimates were performed based on projects determined to be constructible and practical.

Infrastructure and hydrologic modifications will require permits and applications to the NYS and / or FEMA, including construction and environmental permits from the State and accreditation, Letter of Map Revision (LOMR), etc. applications to FEMA. Application and permit costs were not incorporated in the ROM costs estimates.

6.3 ICE JAM FORMATION

An ice jam typically occurs in the late winter and early spring in ice-covered streams when ice accumulates at man-made (e.g. bridge piers, dams) or natural narrower or shallower sections or meanders of a river slowing down or blocking the incoming ice by bridging the ice across the width of the river.

As the air temperature drops, the water temperature reaches freezing temperatures and starts to form frazil ice crystals in the water column. These ice crystals travel in the water column (suspended ice) with the river currents, growing in concentration, and losing heat while traveling. They float on the surface (surface ice), and as the crystals grow in size, they form surface frazil ice. As the air temperature continues to drop, temperature losses from the water and frazil ice create more surface ice, and thicken the existing surface frazil ice, increasing the surface ice concentrations on the river as it approaches colder winter temperatures. The presence of surface and suspended frazil ice increases resistance to the flow, thus increasing the water levels of rivers in the wintertime. Increasing concentrations of surface and suspended frazil ice increase the potential for ice jam formation, which can inhibit the flow of water in the channel, affecting both upstream and downstream water levels.

An existing ice jam can break-up and travel downstream along with larger ice particles with the higher flows of a flash flood and accumulate at a constricted downstream location creating another break-up ice jam, or damage downstream riverbanks or downstream infrastructures severely. Ice-jam flooding presents a complex problem for scientists and engineers since the resulting flood stage can be significantly higher than the flood stage caused from streamflow alone. In other words, a relatively minor discharge of streamflow can result in a major flooding event during an ice jam (USACE 1966).

6.3.1 Ice-Jam Flooding Mitigation Alternatives

There are several widely accepted and practiced standards for ice-jam controls to mitigate the ice-jam related flooding. These are referred to as ice-jam mitigation strategies, and each strategy is very much site dependent. A strategy that works for a certain reach of a river may not work for another reach in the same river due to river morphology and hydrodynamics. Therefore, each of these strategies need to be analyzed with numerical modeling and simulations to check if they work for a considered area / reach of a river before implementing or recommending with the previous observational experience alone. The standard strategies that are widely accepted and practiced in cold-region engineering, such as in Western New York, are listed below with greater detail provided in Appendix F:

- Ice booms
- Ice breaking using explosives
- Ice breaking using ice-breaker ferries and cutters
- Installing inflatable dams (Obermeyer Spillways)
- Mixing heated effluent into the cold water
- Removal of bridge piers, heated bridge piers, or heated riverbank dikes
- Ice retention structures
- Ice forecasting systems and ice management

Ramboll suggests performing a freeze-up or a break-up ice model simulation study prior to implementing any of the above discussed strategies. The basic data needs and steps involved in an ice simulation analysis are also outlined in Appendix F.

6.3.2 Ice-Jam Prone Areas

According to the USACE Cold Regions Research and Engineering Laboratory (CRREL) ice jam database and the effective FEMA FIS, there have been no reported or observed ice-jam events on Eighteenmile Creek (CRREL 2020; FEMA 2019b). However, according to the National Centers for Environmental Information (NCEI) storm events database and the stakeholder engagement meeting for Eighteenmile Creek, there have been two ice-jam incidents that have caused property damages in the watershed since 2014 (NCEI 2020; NYSDEC 2019a). On January 11, 2014, a combination of rainfall and warm temperatures resulted in ice jams on several Buffalo area creeks and streams. In the Town of Boston, ice jams were reported along Eighteenmile Creek in the vicinity of the Patchin Road and Hillcroft Drive bridge crossings. The flooding was minor and total reported property damages from the event was approximately $10,000. More recently, on February 4, 2019, rapid temperature warm-ups occurred across the Buffalo area, which was coming out of below-zero cold temperatures at the end of January. Record warm temperatures resulted in near total snow melt and ice breakup on multiple local rivers and streams. Along Eighteenmile Creek, Heinrich and Eckhardt Roads were closed due to flooding. The flooding was minor, and total reported property damages from the event was approximately $1,000 (NCEI 2020).

Based on historical flood reports found on storm and ice jam databases, news media on the internet, and through the stakeholder engagement meeting, the Town of Boston was identified to be the most adversely affected community by ice-jam flooding in the Eighteenmile Creek basin. Ice-jam flooding on Eighteenmile Creek occurs primarily upstream and in the vicinity of Eckhardt Road and along Back Creek Road in the vicinity of Patchin Road and Hillcroft Drive.

The study area for this report focused on the Town of Boston and includes an analysis of the effects each flood mitigation measures would have on the aforementioned ice jam prone areas. These areas are vulnerable to ice jam flooding due to a combination of infrastructure, development, and channel characteristics in their respective reaches of Eighteenmile Creek. The recent ice-jam flooding of 2014 and 2019 highlights the vulnerability of certain areas along Eighteenmile Creek to ice jam flooding. In order to determine the most appropriate mitigation measures to address ice jam flooding along Eighteenmile Creek, additional hydraulic and hydrologic modeling using ice simulation models and ice jam specific mitigation measures, as outlined in Appendix F, are recommended for each ice jam prone area.

6.4 HIGH RISK AREAS

Based on the FEMA FIS, NCEI storm events database, historical flood reports, and stakeholder input from engagement meetings, three areas along Eighteenmile Creek were identified as high risk flood areas in the Town of Boston.

6.4.1 High Risk Area #1: Eckhardt Road and Surrounding Areas, Town of Boston, NY

High risk area #1 is the area along Eighteenmile Creek in the vicinity of the Eckhardt Road crossing in the Town of Boston located at river station 816+00. The flooding in the vicinity of the Eckhardt Road bridge poses a flood risk threat to: multiple structures both within the FEMA 1% and 0.2% ACE and within 100-ft of the flood zones along Eckhardt and Boston State Roads; Erie County infrastructure for Eckhardt and Boston State Roads; and, NYSDOT infrastructure for the US-219 interchange, including the southbound on-ramp (Figure 6-1).

According to the NYSDOT Functional Class Viewer (https://gis.dot.ny.gov/html5viewer/?viewer=FC), Eckhardt Road is classified as a Urban Major Collector, which is defined as a roadway that provides both land access service and traffic circulation within residential neighborhoods, commercial and industrial areas, and collects traffic from local streets in residential neighborhoods and channels it into the arterial system (NYSDOT 2016a).

The Eckhardt Road crossing and surrounding area is susceptible to open water flooding due to multiple factors, including sediment depositional aggradation restricting the in-channel flow area through this reach and the low elevation of the surrounding topography. Figure 6-2 is the FEMA FIS profile for Eckhardt Road (FEMA 2019b). Eckhardt Road's low chord elevation is unable to pass any of the annual chance flood water surface elevations. The inability to pass high flow events increases the chance for backwater flooding and potential flood damages to areas and properties upstream of the bridge.

In addition to open water flooding, this area is also susceptible to ice jam formations and flooding as discussed in the previous section.

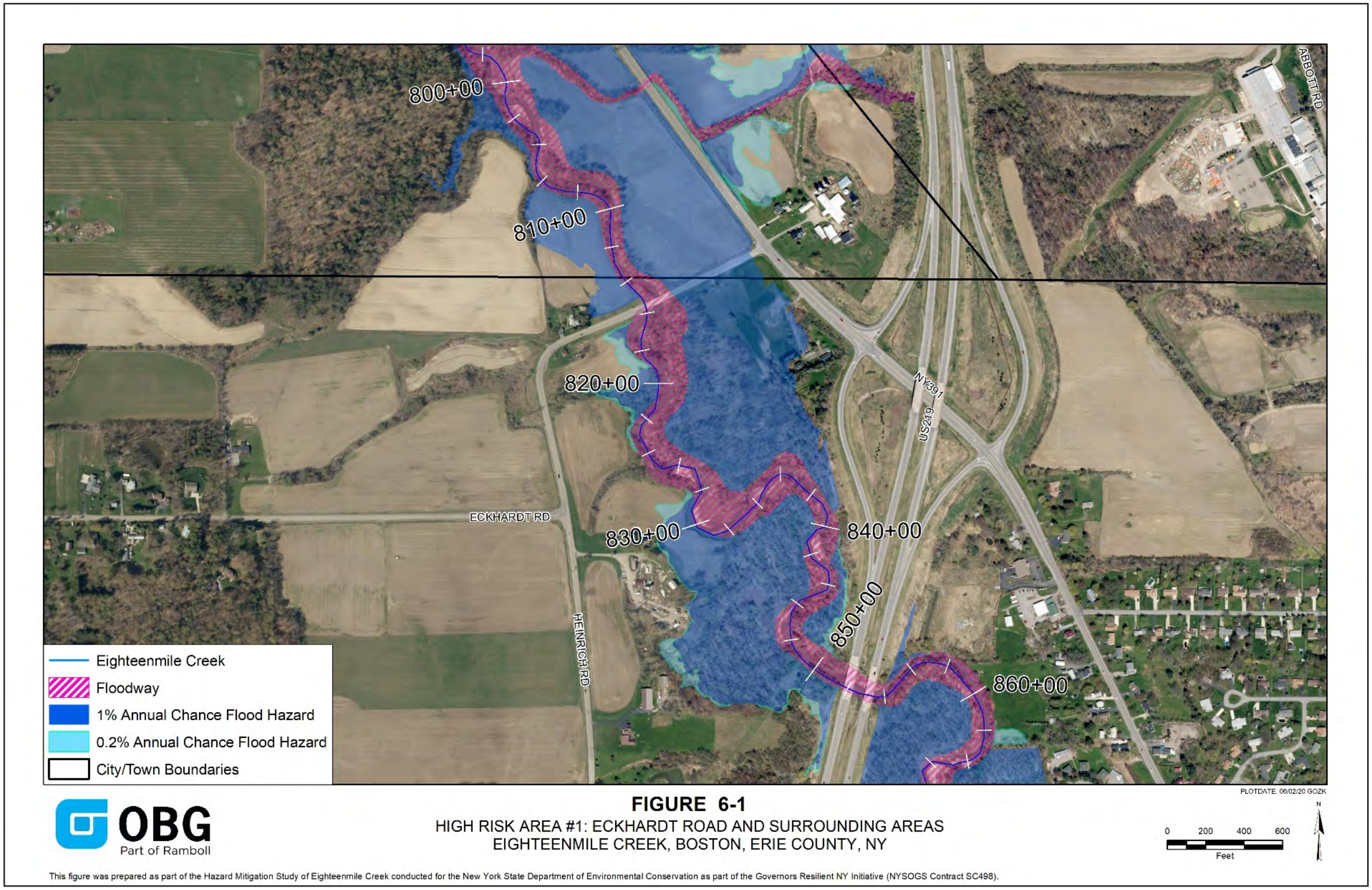

Figure 6-1. High Risk Area #1: Eckhardt Road and Surrounding Areas, Boston, Erie County, NY.

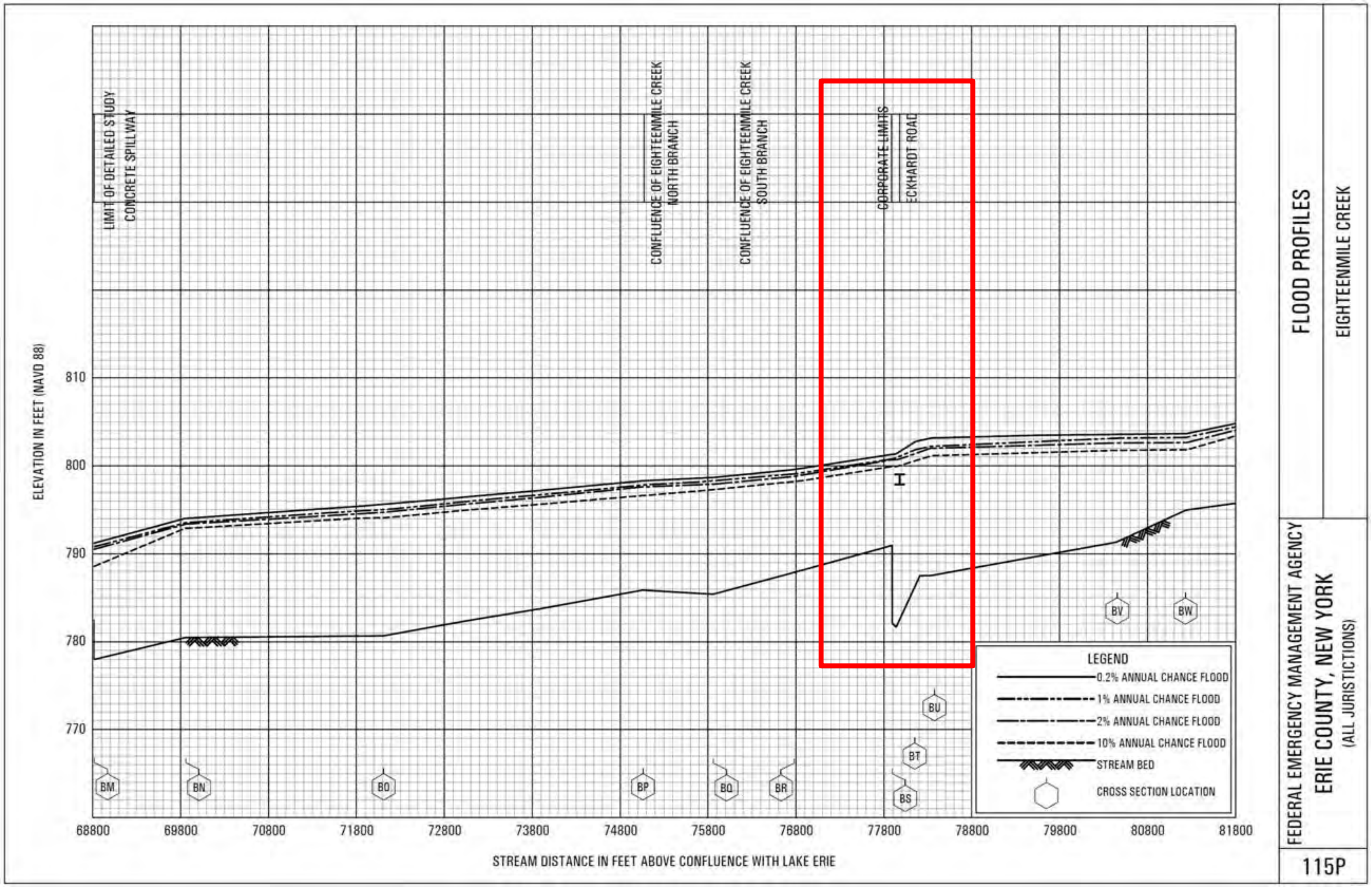

Figure 6-2. FEMA FIS profile for Eighteenmile Creek in the vicinity of Eckhardt Road.

Note: Located at river station 780+00 on the FEMA FIS profile.

6.4.2 High Risk Area #2: Zimmerman Road and Surrounding Areas, Town of Boston, NY

High risk area #2 is the reach of Eighteenmile Creek in the vicinity of Zimmerman Road, which includes the US-219 interchange in the Town of Boston, from river stations 854+00 to 960+00 (Figure 6-3). The Zimmerman Road bridge crossing over Eighteenmile Creek is located at river station 901+50. According to the NYSDOT functional classifications, US-219 is classified as a Principal Arterial Expressway, which is defined as a roadway that serves the major centers of activity of a metropolitan area as the highest traffic volume corridors, and carry a high proportion of the total urban area travel on a minimum mileage, while Zimmerman Road is classified as a Urban Local Street, which is defined as a roadway that offers the lowest level of mobility and serves primarily to provide direct access to abutting land and access to the higher order systems (NYSDOT 2016a).

The US-219 interchange and surrounding area is susceptible to open water flooding due to multiple factors, including sediment depositional aggradation restricting the in-channel flow area along Eighteenmile Creek through this reach and multiple residential subdivisions being built directly adjacent to the creek. Figure 6-4 is the FEMA FIS profile for Zimmerman Road (FEMA 2019b). Zimmerman Road's low chord elevation is unable to pass flood events below the 1% annual chance level (e.g. high flow events greater than the 100-year recurrence interval). The inability for this bridge to pass high flow events increases the chance for backwater flooding and potential flood damages to areas and properties both downstream and upstream of bridge.

Residential neighborhoods adjacent to Eighteenmile Creek in this reach are at a higher risk of flood damages due to their close proximity to the creek channel and current lack of flood protection measures.

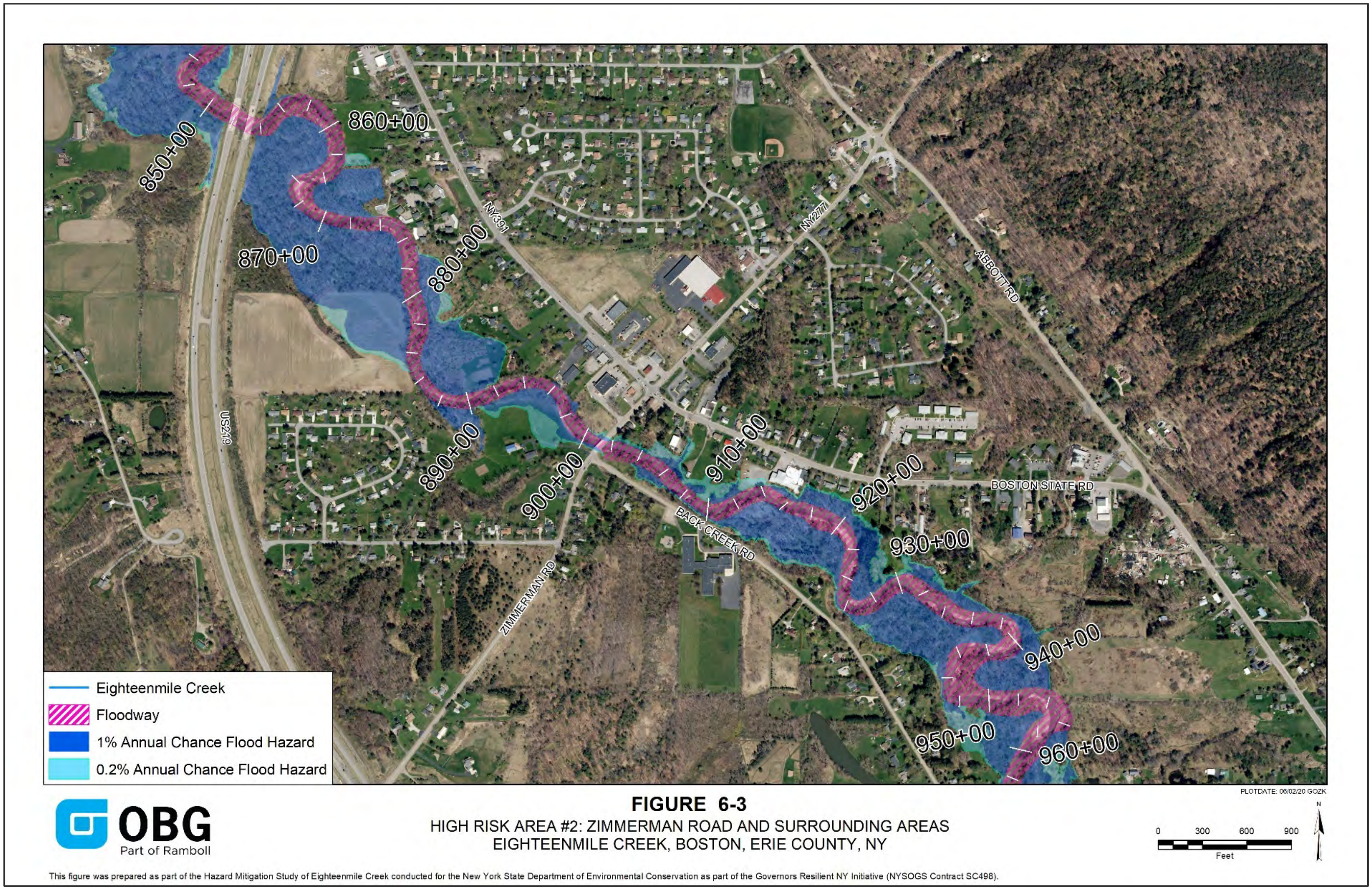

Figure 6-3. High Risk Area #2: Zimmerman Road and Surrounding Areas, Boston, Erie County, NY.

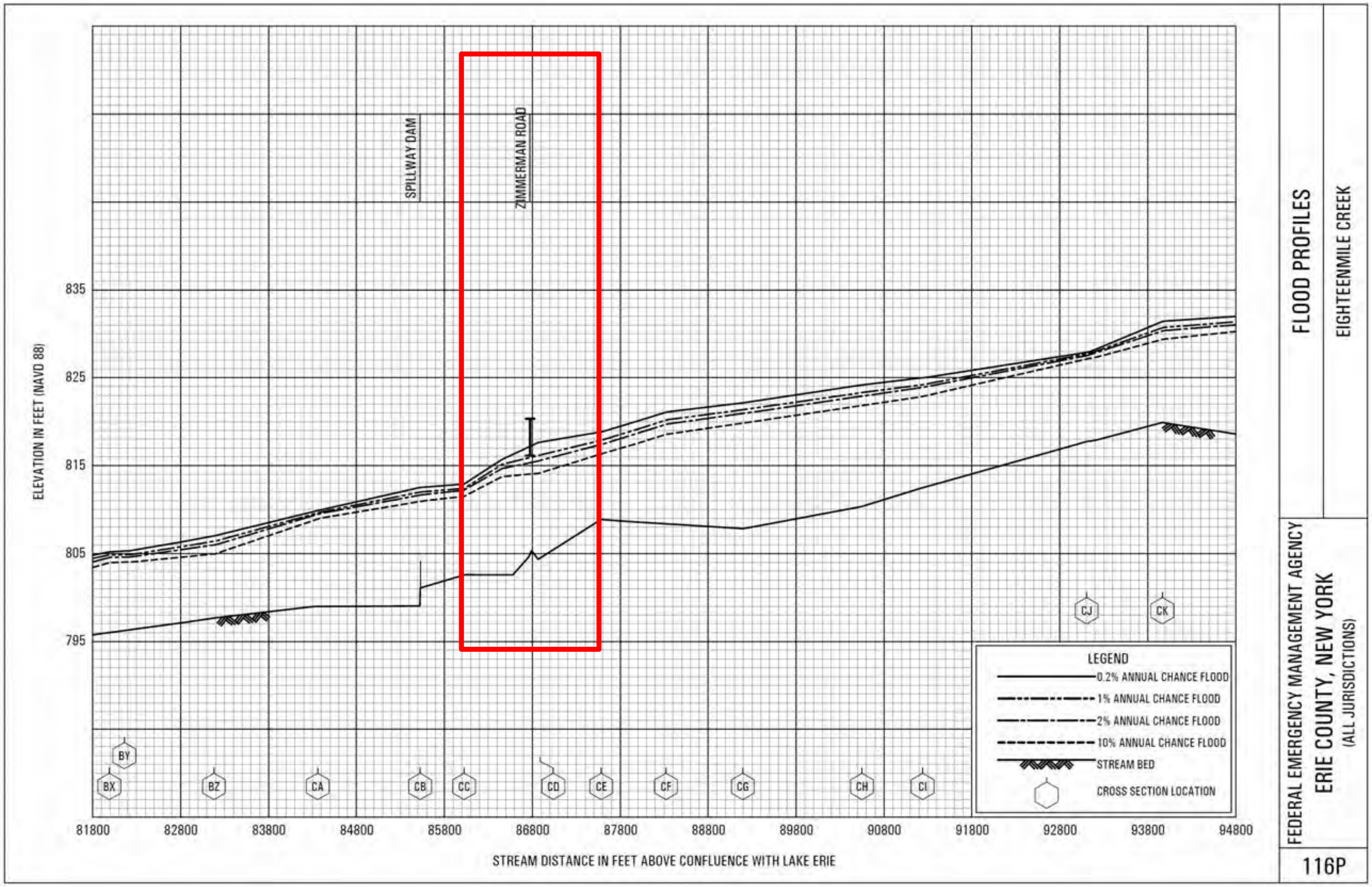

Figure 6-4. FEMA FIS profile for the Zimmerman Road bridge crossing.

Note: Located at river station 868+00 on the FEMA FIS profile.

6.4.3 High Risk Area #3: Back Creek Road (County Road 438) and Surrounding Areas, Town of Boston, NY

High risk area #3 is along Back Creek Road in the hamlet of Patchin, beginning downstream of the Patchin Road bridge crossing and extending upstream approximately 6,000-feet (Figure 6-5). The Patchin Road crossing is located at river station 1087+00. According to the NYSDOT functional classifications, Back Creek Road is classified as Urban Local Street, which is defined as roadways that offer the lowest level of mobility and serve primarily to provide direct access to abutting land and access to the higher order systems (i.e. collectors, arterials, etc.) (NYSDOT 2016a).

Eighteenmile Creek near Back Creek Road in the vicinity of Patchin Road is susceptible to open water flooding due to multiple factors, including steep valley terrain concentrating precipitation into the creek and debris and sediment depositional aggradation. Figure 6-6 is the FEMA FIS profile for Patchin Road (referred to as County Road 444/Shero Road) which indicates that the bridge is able to pass all annual chance flood events (FEMA 2019b). The FEMA FIRM for the area indicates that stream flow remains within the channel upstream of the bridge, but overtops the channel banks immediately downstream of Patchin Road (FEMA 2019a). Based on the LiDAR DEM data and FIS water surface elevation profiles, the channel overbank elevations downstream Patchin Road are lower than the 10, 2, 1, and 0.2% ACE water surface elevations. As a result, downstream areas have a high potential to experience flood damages from moderate to high flow events along Eighteenmile Creek in the vicinity of Patchin Road.

In addition, the steep valley terrain acts to concentrate precipitation and runoff into Eighteenmile Creek (Figure 6-7). Eroded sediments from the valley terrain are carried by runoff into the creek channel and can cause aggradation to occur, which restricts the in-channel flow area and increases the risk of open water and ice jam flooding. This process is evidenced by the numerous sediment and sand bars along the creek path in this reach.

In addition to open water flooding, this area is also susceptible to ice-jam formations and flooding as discussed in the previous section.

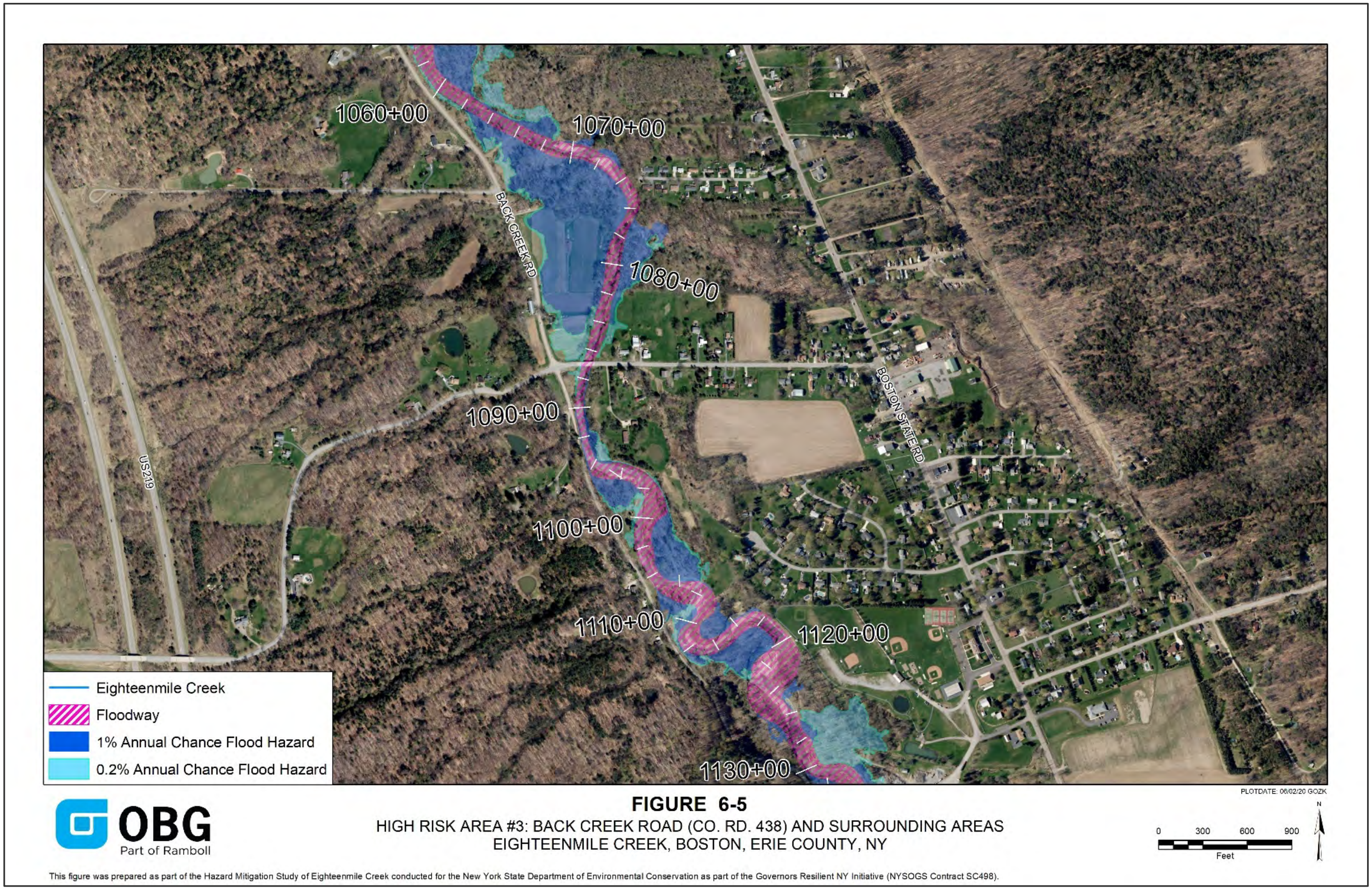

Figure 6-5. High Risk Area #3: Back Creek Road, Boston, Erie County, NY.

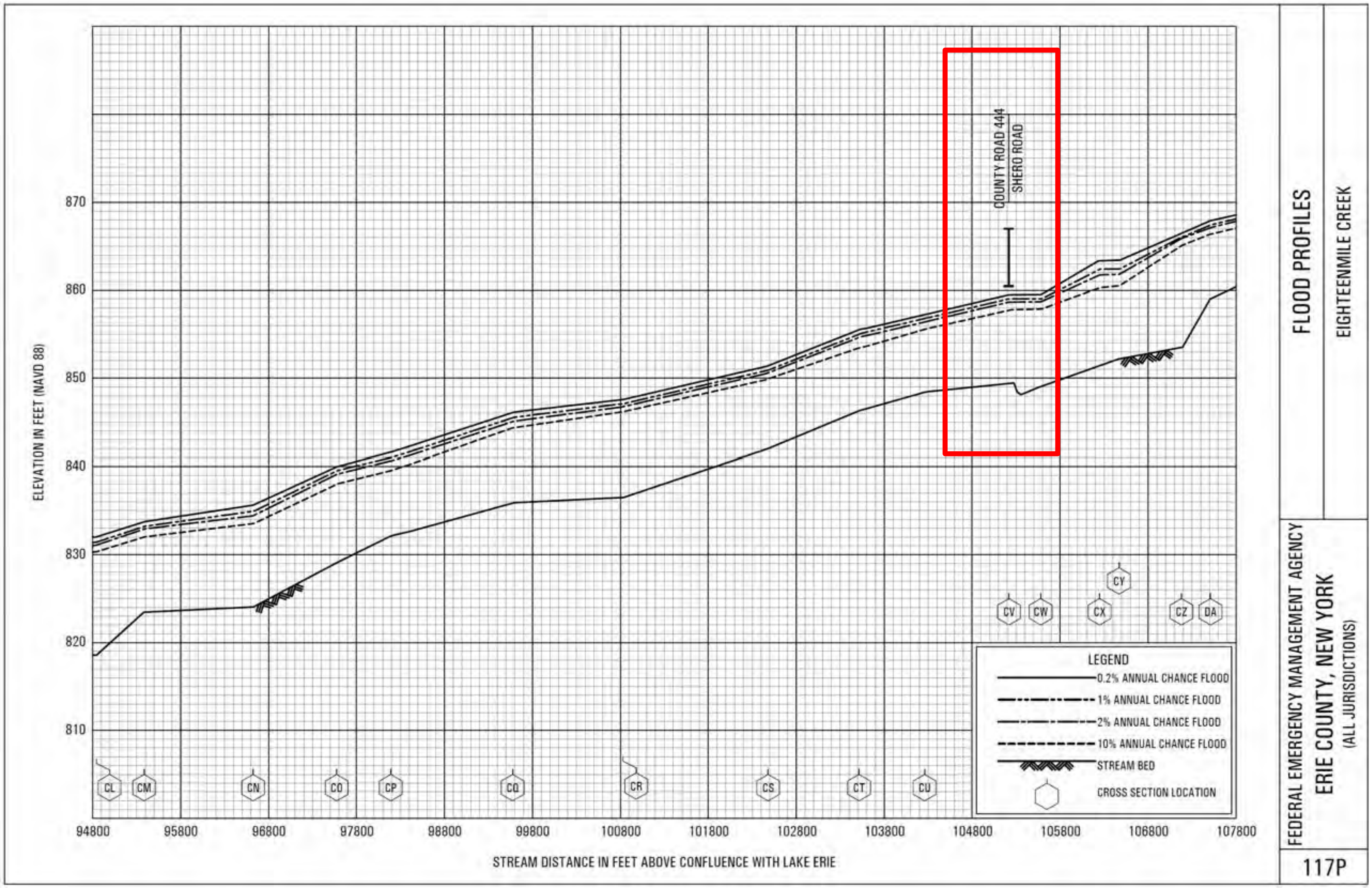

Figure 6-6. FEMA FIS profile for the Patchin Road bridge crossing (County Road 444 / Shero Road).

Note: Located at river station 1052+00 on the FEMA FIS profile.

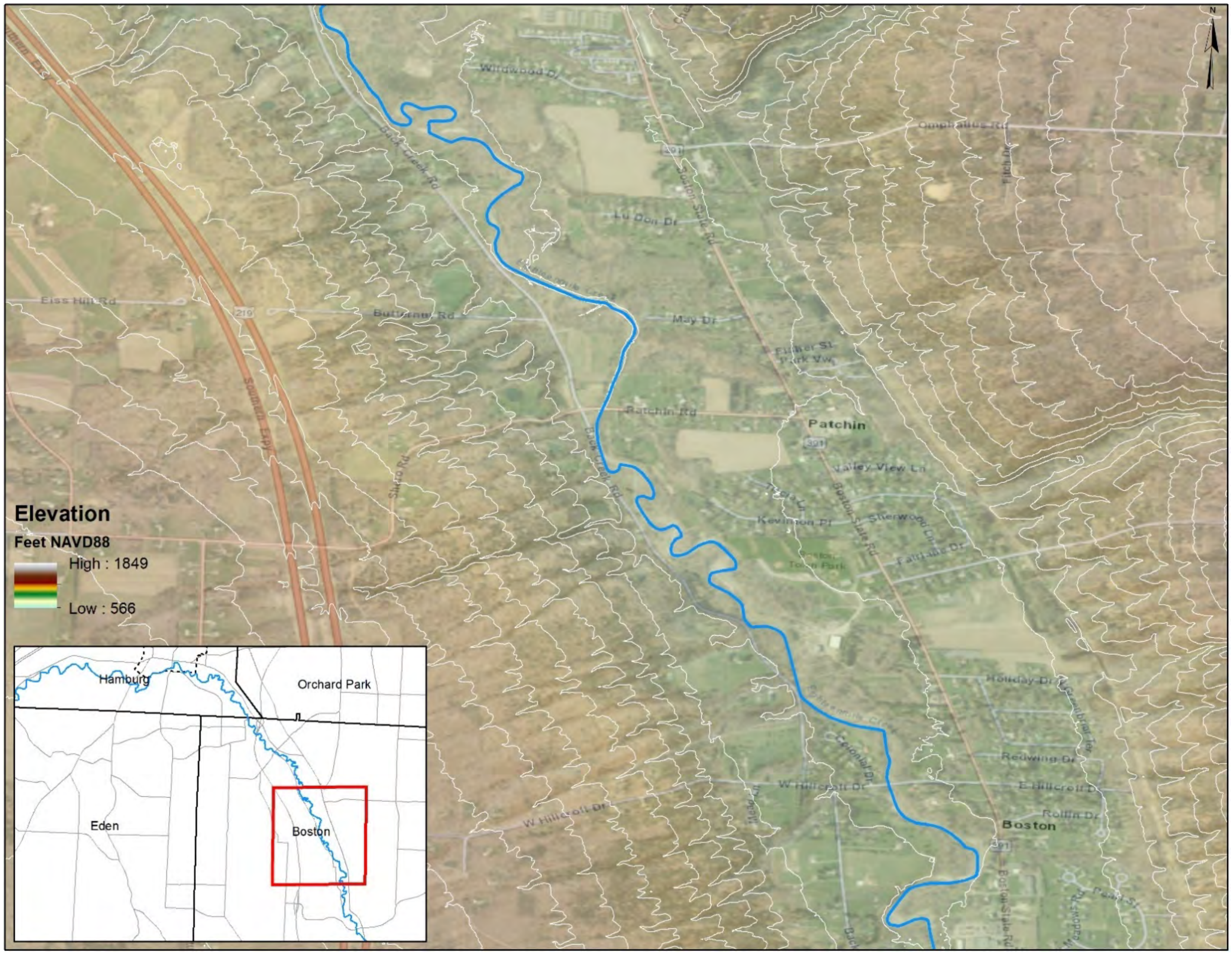

Figure 6-7. Terrain plot of Eighteenmile Creek with 50-ft elevation contours (white) in the vicinity of Patchin Road.

7. MITIGATION RECOMMENDATIONS

7.1 HIGH-RISK AREA #1

7.1.1 Alternative #1-1: Flood Benches Upstream of Eckhardt Road

Installing a flood bench would provide additional storage and floodplain width, which could potentially reduce flood damages in the event of flooding and address issues within high-risk area #1. The benches are located within FEMA's designated Regulatory Floodway and Zone AE. The Regulatory Floodway is defined as the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than 1-foot over the 1% annual chance flood hazard water surface elevation. Zone AE are areas that have a 1% annual chance of flooding where BFEs are provided by FEMA (FEMA 2000; FEMA 2019a).

The flood benches would potentially benefit and reduce the flood risk for the properties along Eckhardt and Heinrich Roads adjacent to and immediately upstream of the bridge crossing in close proximity to Eighteenmile Creek. Flood Bench A is located on the right bank of Eighteenmile Creek, while Bench B is located on the left bank, with both benches being upstream the Eckhardt Road bridge crossing in the Town of Boston. Bench A is between river stations 820+00 to 836+00 and Bench B is between river stations 831+00 to 848+00 (Figure 7-1). The total acreage of both Bench A and B is 4.5 acres with a minimum elevation of 796-feet NAVD88 and 798-feet NAVD 88, respectively. Appendix E provides mitigation renderings which depict the landscape characteristics of a flood bench.

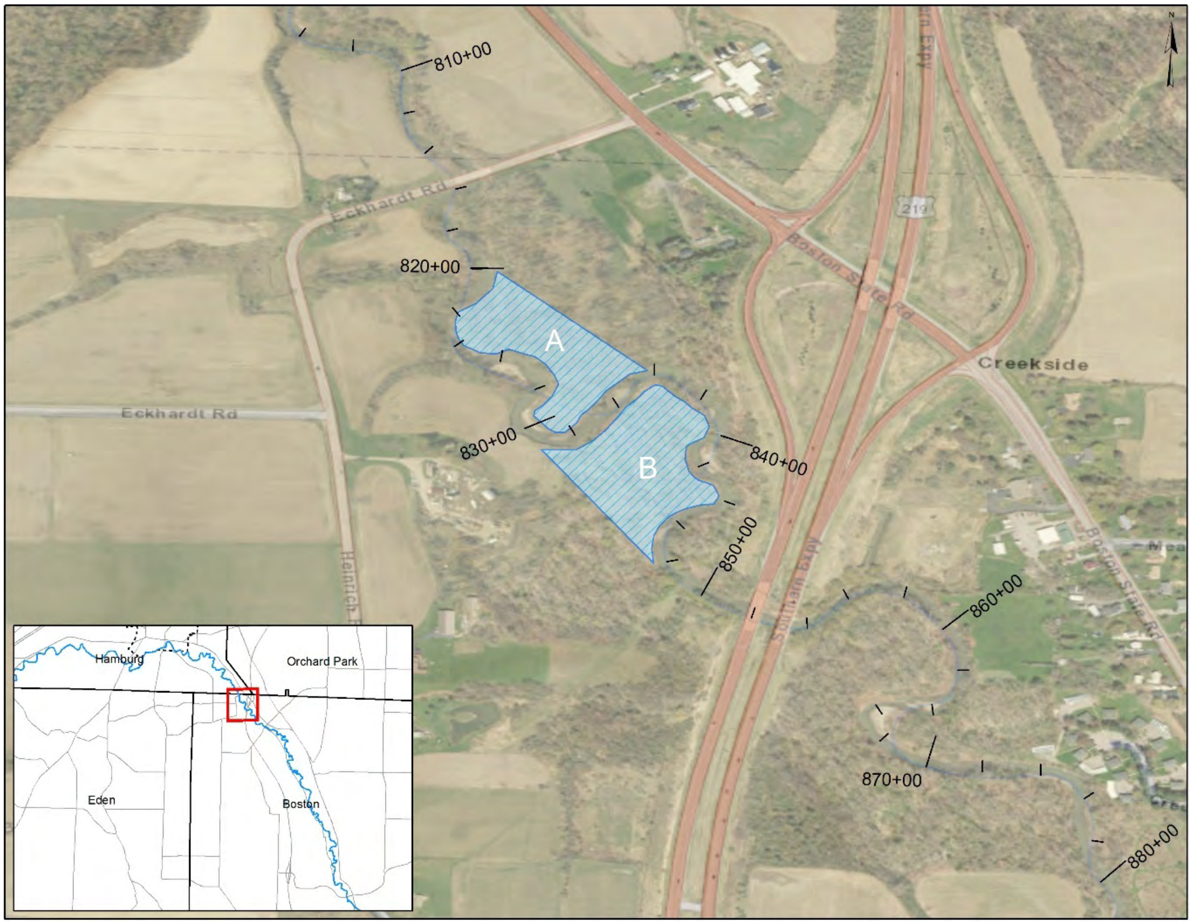

Figure 7-1. Location map for Alternative #1-1.

The proposed condition modeling simulation confirmed that the Eckhardt Road bridge crossing is in a high-risk flood area. The model results simulated water surface reductions of up to 1.5-feet in areas adjacent to and immediately upstream of the flood benches (Figure 7-2). The modeling output for future conditions displayed similar results with water surface elevations up to 0.5-feet higher due to the increased discharges associated with predicted future flows in Eighteenmile Creek.

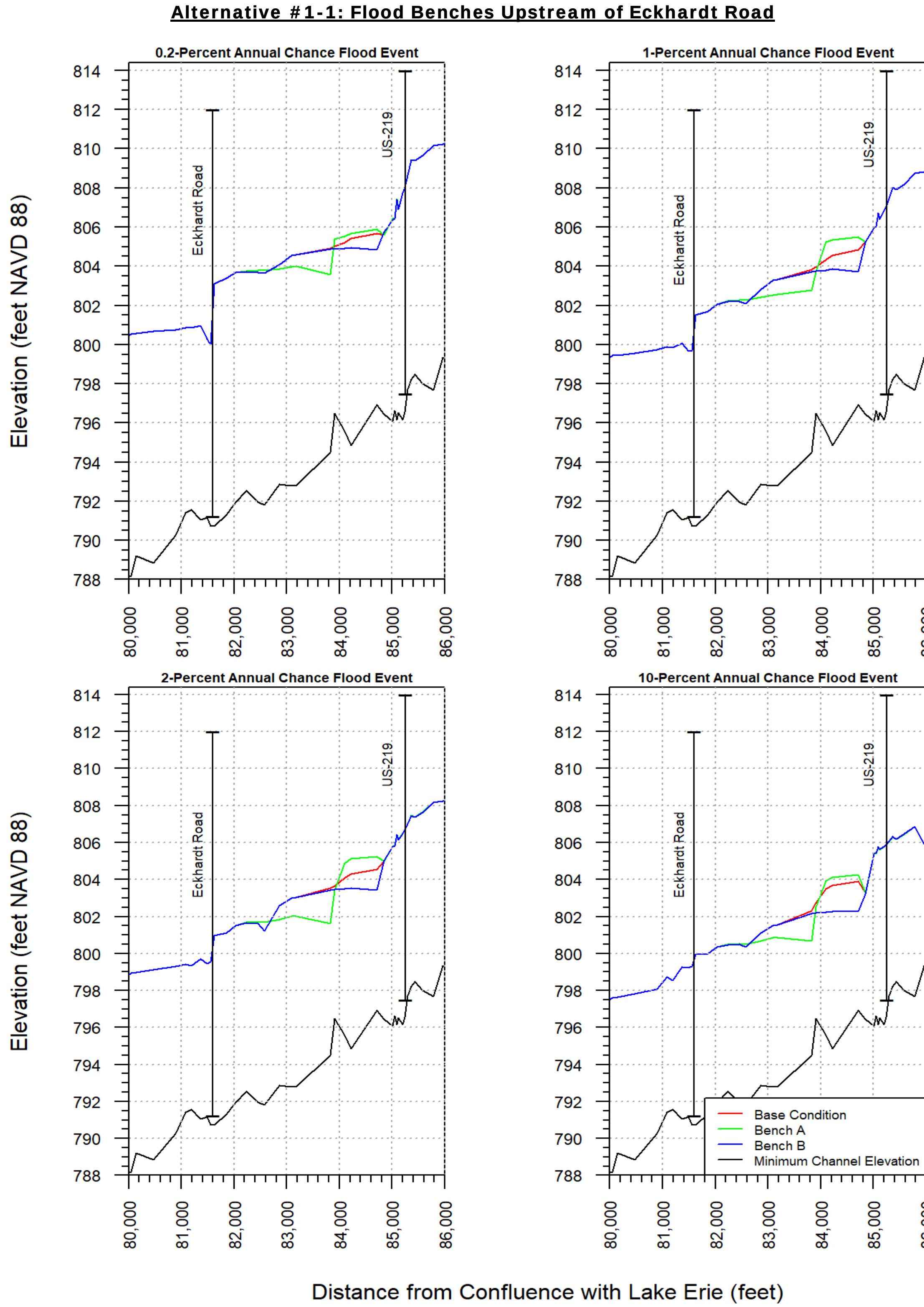

Figure 7-2. HEC-RAS model simulation output results for Alternative #1-1.

Table 14 is a summary of the simulations and results with river stationing, acreage, and maximum water surface elevation reductions according to model simulation results.

Table 14. Summary of Alternative #1-1 Simulations and Results

Simulation ID	River Station (ft)	Acreage (ac)	Maximum Water Surface Reduction (ft)
Bench A	820+00 to 836+00	4.5	Up to 1.5-ft
Bench B	831+00 to 848+00	4.5	Up to 1.4-ft

To assess the influence of ice jams in the vicinity of Eckhardt Road, an ice cover simulation with 1-foot ice thickness was performed for each flood scenario. The simulations were intended to mimic the effects of an ice jam upstream and in the vicinity of the Eckhardt Road bridge crossing, which would reduce cross-sectional area and increase the in-channel roughness. When compared to existing conditions with ice cover, the simulation results indicated that for a 10% annual chance flood hazard event (i.e. 10-year flood) event with approximately 3,140 cfs and a 1-foot thick ice cover, water surface elevations would be reduced by up to 1.2-feet for Bench A and up to 1-foot for Bench B (Figure 7-3). The reduction in water surface elevations for both bench scenarios occurs well upstream of the Eckhardt Road bridge crossing and water surfaces return to “normal” levels as flow pass under the bridge.

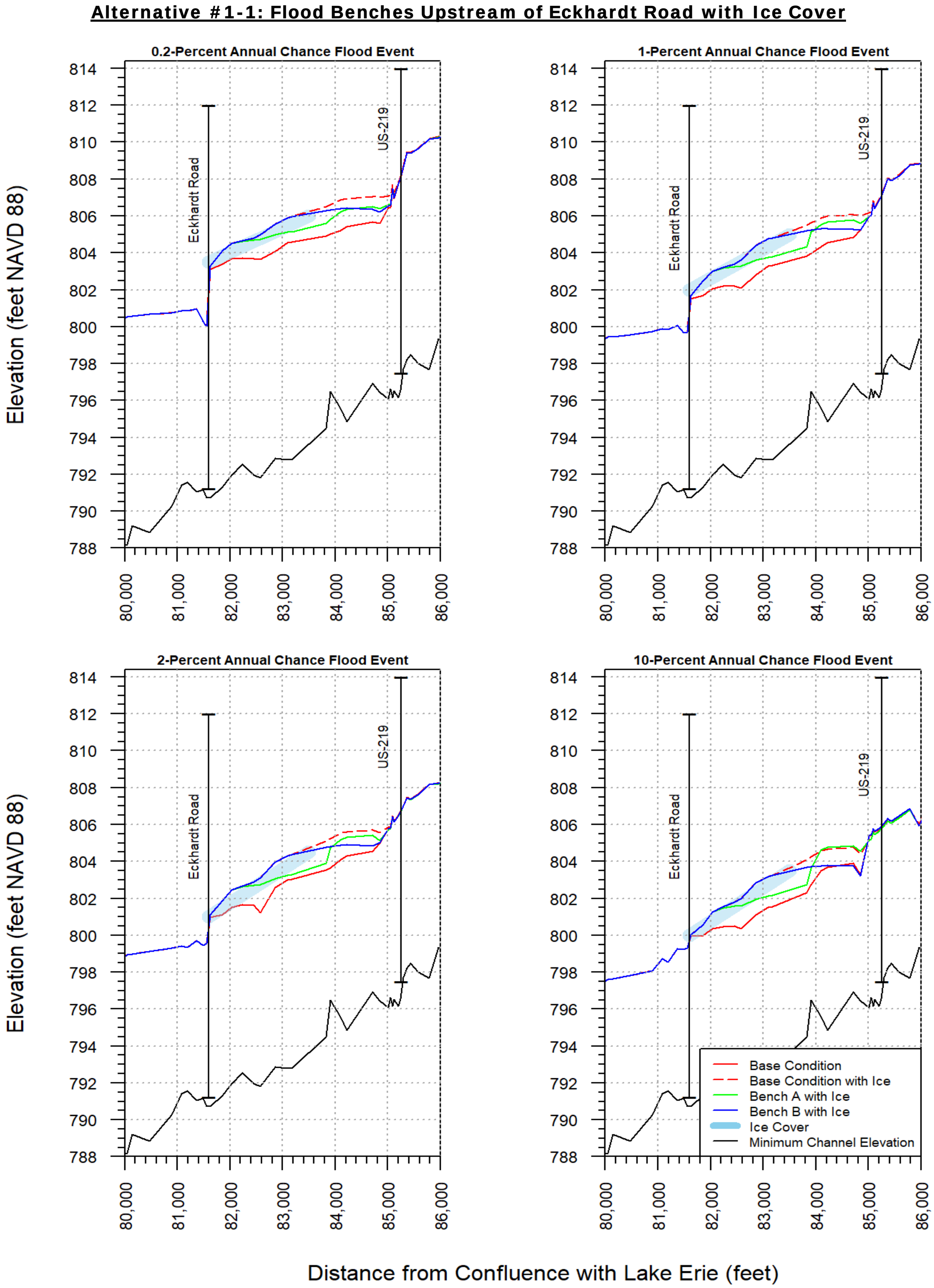

Figure 7-3. HEC-RAS ice cover model simulation output results for Alternative #1-1.

Flood benches generally provide flood protection for localized areas in the vicinity of and immediately upstream and / or downstream of the bench. Based on the analysis of high-risk areas, a flood bench located upstream the Eckhardt Road bridge crossing would provide some protection to the properties in this reach from both open water and ice-jam related flooding.

The potential benefits of this strategy are limited to the areas in the vicinity of and immediately upstream of the flood bench, specifically between river stations 825+00 to 853+00 for Bench A, and 835+00 to 860+00 for Bench B.

The Rough Order Magnitude cost for Bench A is $2.1 Million, and Bench B is $1.8 Million, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

7.1.2 Alternative #1-2: Widen Eckhardt Road Bridge

This measure is intended to address issues within high-risk area #1 by increasing the width of the Eckhardt Road bridge opening, which would increase the cross-sectional flow area of the channel located at river station 816+00 (Figure 7-4). This bridge is owned by Erie County, NY and has no piers in the channel. The existing bridge structure has a bridge span of 82-ft and maximum low chord to channel bottom height of 21-ft (NYSDOT 2016b; OBG 2020). The flooding in the vicinity of the Eckhardt Road bridge poses a flood risk threat to: multiple structures both within the FEMA 1% and 0.2% ACE and within 100-ft of the flood zones along Eckhardt and Boston State Roads; Erie County infrastructure for Eckhardt and Boston State Roads; and, NYSDOT infrastructure for the US-219 interchange, including the southbound on-ramp.

According to the FEMA FIS, there is backwater upstream of the Eckhardt Road bridge at annual chance flood levels less than or equal to 10% and the bridge does not provide the NYSDOT recommended 2-feet of freeboard over the 2% annual chance flood water surface elevation. The constriction of flow in the channel increases the potential for ice-jam formation and backwater flooding upstream of the bridge (FEMA 2019b). This measure would potentially benefit and reduce the flood risk for the properties adjacent to and immediately upstream Eckhardt Road.

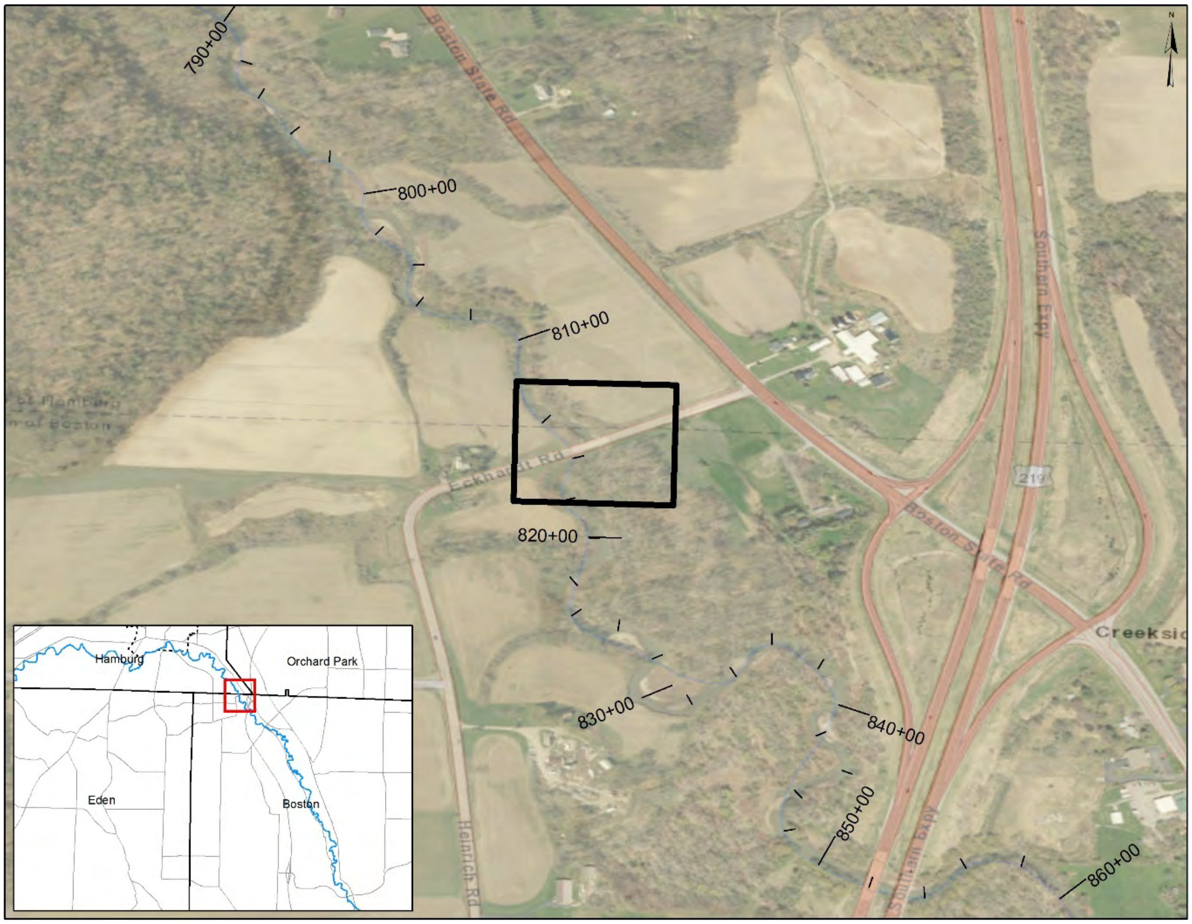

Figure 7-4. Location map for Alternative #1-2.

The proposed condition modeling confirmed that the Eckhardt Road bridge is a constriction point along Eighteenmile Creek. The bridge widening scenario increased the cross-sectional flow area of the bridge on both sides of the channel by approximately 50% of the current flow area and a new bridge span of 123-feet. The proposed condition modeling simulation results indicated water surface reductions for high flow events only (i.e. less than 2% annual chance flood hazard) of up to 0.5-foot in areas immediately upstream of the bridge (Figure 7-5). The modeling output for future conditions displayed similar results with water surface elevations up to 0.5-foot higher due to the increased discharges associated with predicted future flows in Eighteenmile Creek.

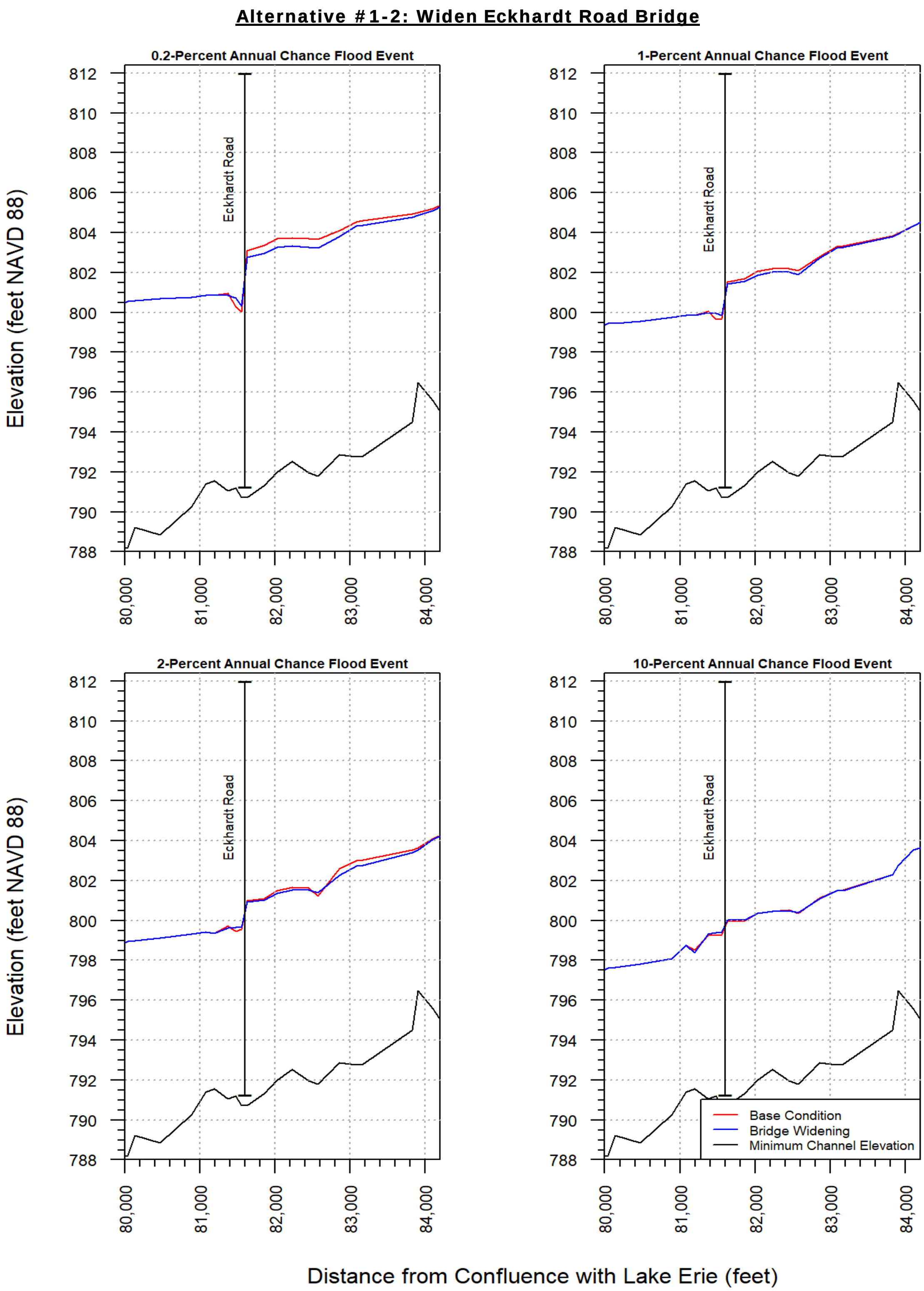

Figure 7-5. HEC-RAS model simulation output results for Alternative #1-2.

To assess the influence of ice jams on the Eckhardt Road bridge, an ice cover simulation with 1-foot ice thickness was performed. This simulation was intended to mimic the effects of an ice jam upstream of the bridge, which would reduce cross-sectional area and increase the in-channel roughness. When compared to existing conditions with ice cover, the simulation results indicated that for a 10% annual chance flood hazard event (i.e. 10-year flood) with approximately 3,140 cfs and a 1-foot thick ice cover, water surface elevations were reduced up to 0.1-foot immediately upstream of the bridge. For high flow events (i.e. less than 2% annual chance flood hazard) there were simulated water surface elevation reductions of up to 0.5-foot in areas immediately upstream of the bridge (Figure 7-6).

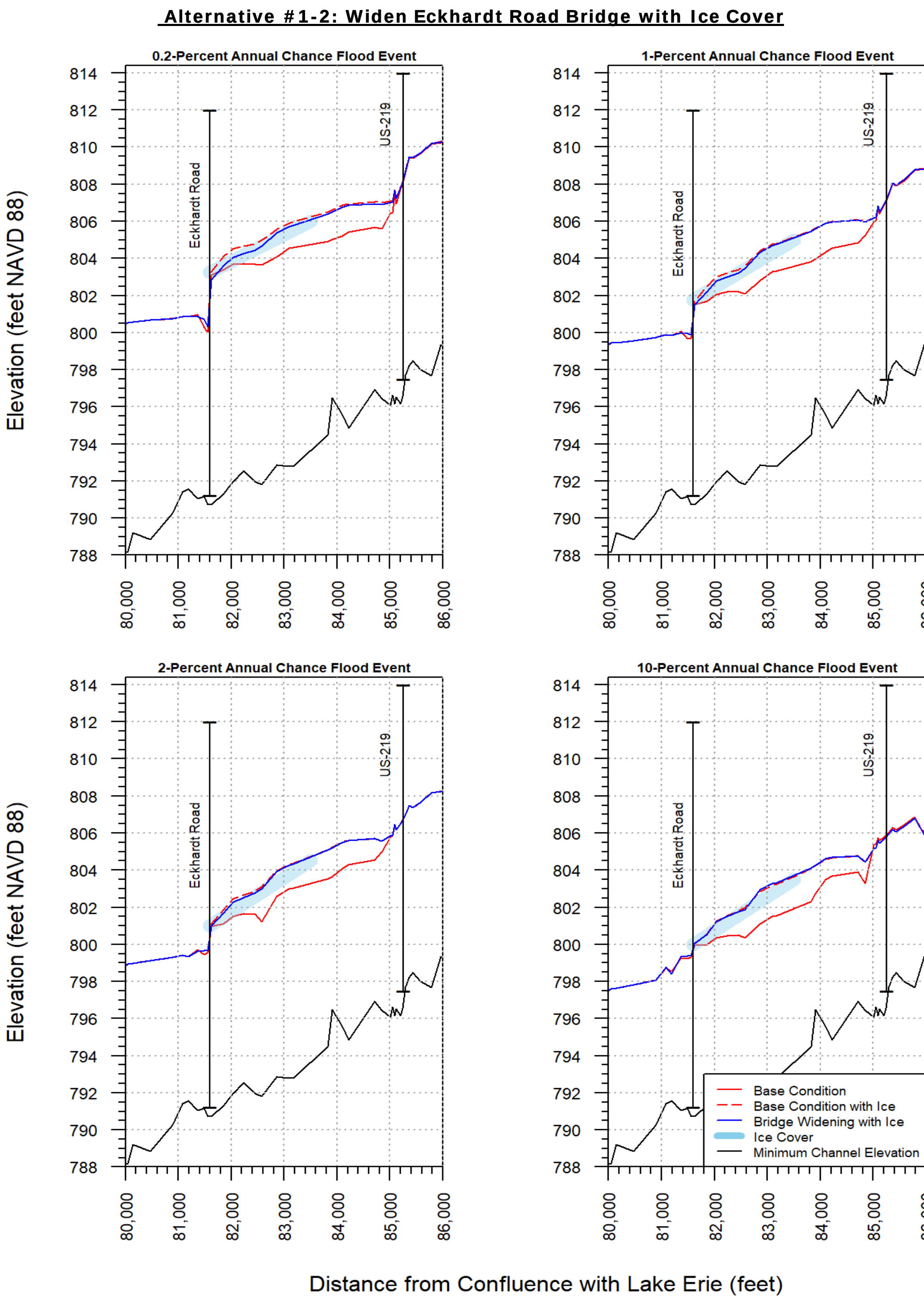

Figure 7-6. HEC-RAS ice cover model simulation output results for Alternative #1-2.

The Eckhardt Road bridge experiences sediment depositional aggradation in this reach and the hydraulic and hydrologic influence of the US-219 bridge crossing located 3,500-feet upstream. In addition, the ground elevation of the areas adjacent to Eckhardt Road are lower than the bridge and its abutments, which are the high point along the roadway. As a result, water that overtops the banks of Eighteenmile Creek in the vicinity of Eckhardt Road continue to flow downstream and flood adjacent areas, as evidenced in the FEMA FIRM and FIS profiles (FEMA 2019a; FEMA 2019b).

In addition, when ice cover forms in the creek upstream and an ice breakup event occurs, ice pieces can get caught on debris and sediment deposits in the creek as they approach the Eckhardt Road bridge and along the abutments of the bridge. All of these factors act to influence water flow in the channel, increasing the potential for ice-jam formation and backwater flooding. In theory, widening the bridge can increase the cross-sectional area of the creek channel in the vicinity of the bridge, allowing more ice pieces and water to flow downstream and potentially reducing the risk of ice-jam formations and flooding. Based on the model simulation results, widening the Eckhardt Road bridge would achieve reductions in both open-water and ice-jam flooding potential.

The Rough Order Magnitude cost for this measure is $2.8 Million.

7.2 HIGH-RISK AREA #2

7.2.1 Alternative #2-1: Flood Benches Downstream of Zimmerman Road

Installing a flood bench would provide additional storage and floodplain width, which could potentially reduce damages in the event of flooding and address issues within high-risk area #2. Four different flood benches were modeled at various locations downstream of the Zimmerman Road bridge crossing (Figure 7-7). The total acreage of the flood benches varied from two to six acres. All four flood benches are located within the FEMA Regulatory Floodway or Zone AE (FEMA 2000; FEMA 2019a). The flood benches would potentially benefit and reduce the flood risk for the properties along Boston State Road downstream of Zimmerman Road up to the US-219 expressway that are in close proximity to Eighteenmile Creek.

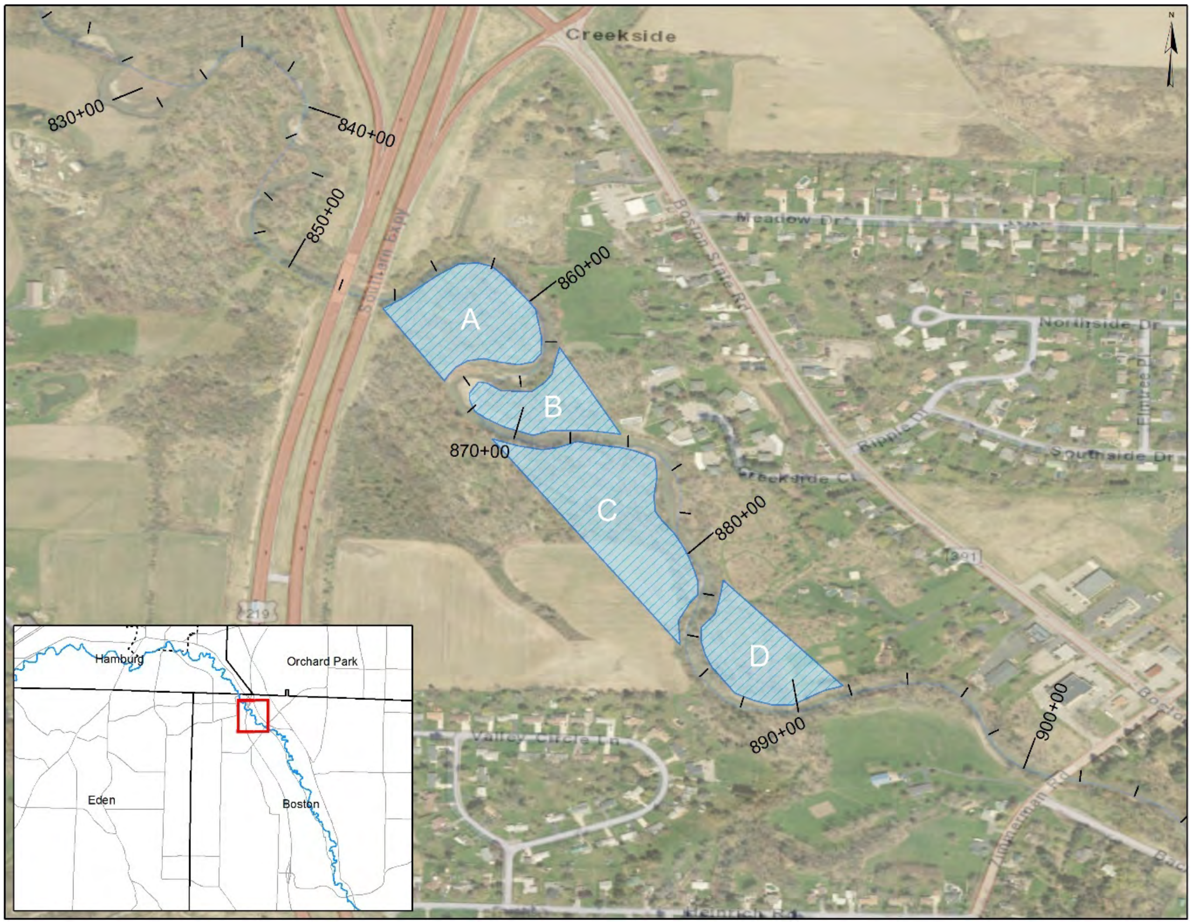

Figure 7-7. Location map for Alternative #2-1.

Table 15 is a summary of the simulations and results with river stationing, acreage, and maximum water surface elevation reductions according to model simulation results.

Table 15. Alternative #2-1 HEC-RAS Simulation Results

Simulation ID	River Station (ft)	Acreage (ac)	Minimum Channel Elevation (ft NAVD88)	Maximum Water Surface Reduction (ft)
Bench A	854+00 to 866+00	4.0	802	Up to 1.4-ft
Bench B	82+00 to 874+00	2.3	804	Up to 0.5-ft
Bench C	869+00 to 884+00	6.0	804	Up to 0.9-ft
Bench D	882+00 to 892+00	3.0	807	Up to 1.7-ft

The proposed condition modeling simulation confirmed that the Eckhardt Road bridge crossing is in a high-risk flood area. The model results simulated water surface reductions of up to 1.7-foot in areas adjacent to and immediately upstream of the flood benches (Figure 7-8). The modeling output for future conditions displayed similar results with water surface elevations up to 0.5-foot higher due to the increased discharges associated with predicted future flows in Eighteenmile Creek.

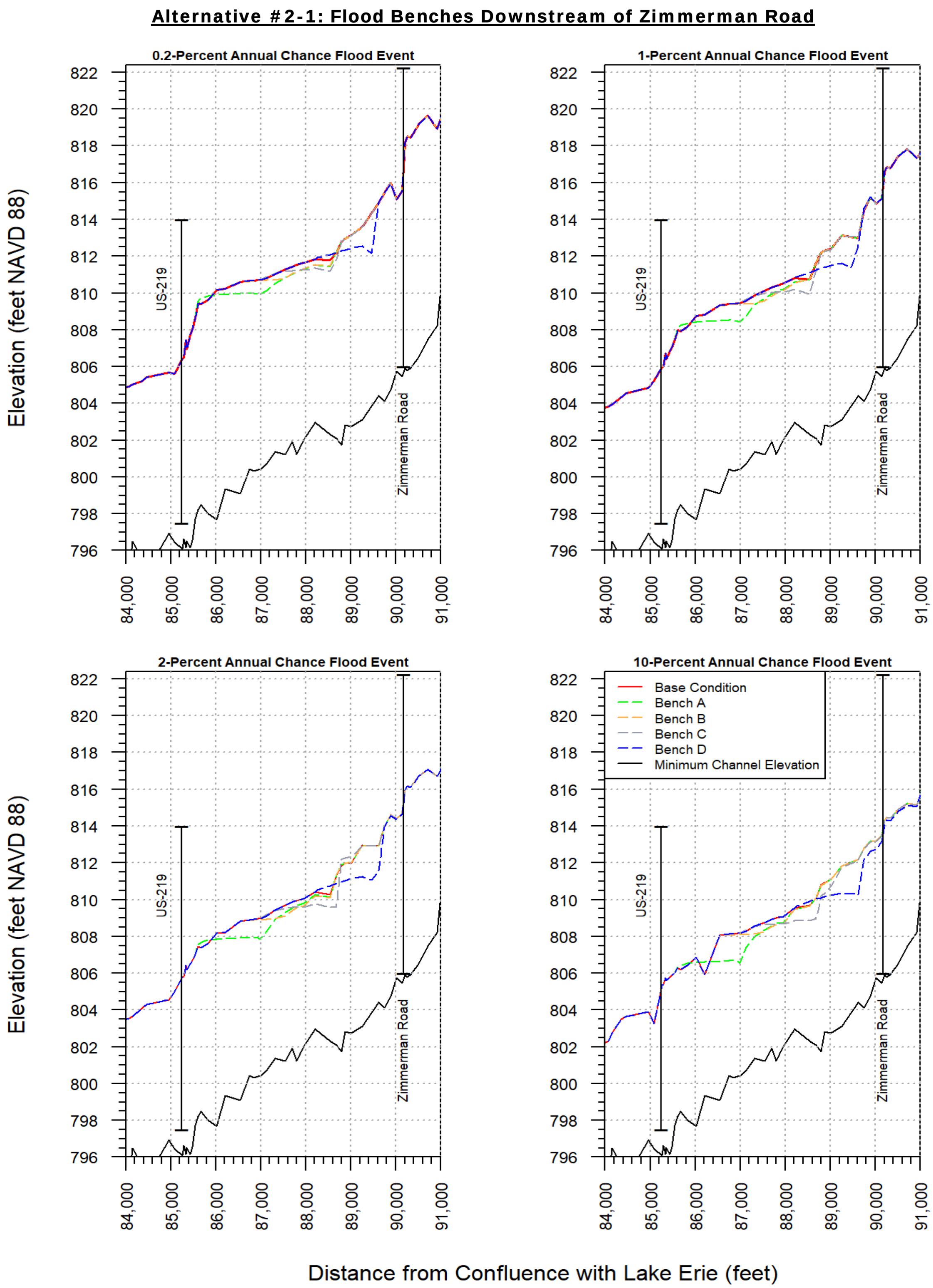

Figure 7-8. HEC-RAS model simulation output results for Alternative #2-1

Flood benches generally provide flood protection for localized areas in the vicinity of and immediately upstream and / or downstream of the bench. Based on the analysis of high-risk areas, a flood bench located upstream the US-219 bridge crossing would provide some protection to the properties in this reach from open water flooding.

The potential benefits of each bench and their associated Rough Order Magnitude cost, not including land acquisition costs for survey, appraisal, and engineering coordination, are listed in Table 16.

Table 16. Alternative #2-1 potential benefits and ROM cost summary

Simulation ID	Potential Benefitted Area (ft)	ROM cost ($ U.S. dollars)
Bench A	853+00 to 889+50	$2.0 Million
Bench B	863+00 to 891+00	$930,000
Bench C	870+00 to 898+00	$2.4 Million
Bench D	883+00 to 900+00	$1.4 Million

7.2.2 Alternative #2-2: Widen Zimmerman Road Bridge

This measure is intended to address issues within high-risk area #2 by increasing the height and width of the Zimmerman Road bridge opening, which would increase the cross-sectional flow area of the channel located at river station 901+50 (Figure 7-9). This bridge is owned by Erie County, NY and has no piers in the channel. The existing bridge structure has a bridge span of 78-ft and maximum low chord to channel bottom height of 16.5-ft (NYSDOT 2016b; OBG 2020).

According to the FEMA FIS, backwater occurs upstream of the Zimmerman Road bridge at annual chance flood levels less than or equal to 1% and the bridge does not provide the NYSDOT recommended 2-feet of freeboard over the 2% annual chance flood water surface elevation. In addition, the constriction of flow in the channel increases the potential for ice-jam formation and backwater flooding upstream of the bridge (FEMA 2019b). This measure would potentially benefit and reduce the flood risk for the properties adjacent to and immediately upstream Zimmerman Road.

Figure 7-9. Location map for Alternative #2-2.

The proposed condition modeling confirmed that the Zimmerman Road bridge is a constriction point along Eighteenmile Creek. The bridge widening scenario increased the cross-sectional flow area of the bridge on both sides of the channel by approximately 50% of the current flow area and a new bridge span of 112-feet. The cross-sectional flow area was enlarged by increasing the horizontal width of the bridge opening.

The model results simulated water surface reductions of up to 0.2-foot in areas adjacent to and immediately upstream of the flood benches (Figure 7-10). The modeling output for future conditions displayed similar results with water surface elevations up to 0.5-foot higher due to the increased discharges associated with predicted future flows in Eighteenmile Creek.

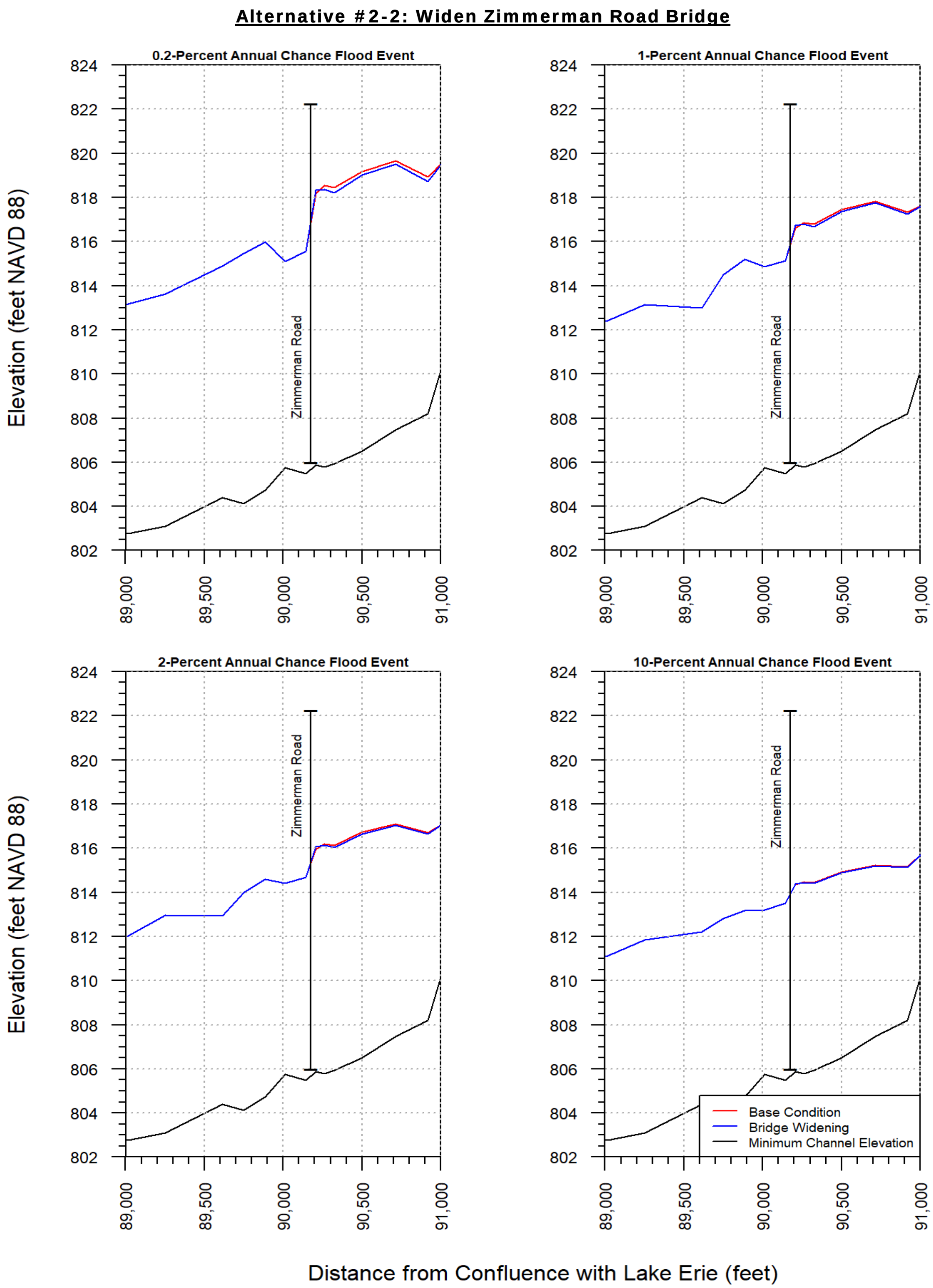

Figure 7-10. HEC-RAS model simulation output results for Alternative #2-2.

Zimmerman Road is located approximately 4,600-feet upstream of the US-219 bridge crossing. There are significant meanders in Eighteenmile Creek both upstream and downstream where sediment depositional aggradation has occurred creating sediment and sand bars. These sediment and sand bars restrict in-channel flow areas and cause water velocities to slow and water surfaces to rise as the flow reaches the Zimmerman Road bridge crossing. During higher discharge events, backwater occurs upstream of the bridge increasing the potential for open-water flooding.

The potential benefits of this strategy are limited to the areas in the vicinity of and immediately upstream of the Zimmerman Road bridge crossing, specifically between river stations 895+00 to 905+00.

Based on the analysis of the bridge widening simulation, this strategy is not recommended due to the ineffectiveness of the measure to provide adequate flood protection to areas both up and downstream of Zimmerman Road, and additional costs associated with widening a bridge.

The Rough Order Magnitude cost for this measure is $3 Million.

7.2.3 Alternative #2-3: Flood Benches Upstream of Zimmerman Road

Installing a flood bench would provide additional storage and floodplain width, which could potentially reduce damages in the event of flooding and address issues within high-risk area #2. Five different flood benches were modeled at various locations upstream of the Zimmerman Road bridge crossing (Figure 7-11). The total acreage of the flood benches varied from 2.0 to 5.5 acres. All five flood benches are located within the FEMA Regulatory Floodway or Zone AE (FEMA 2000; FEMA 2019a). The flood benches would potentially benefit and reduce the flood risk for the properties along Boston State Road upstream of Zimmerman Road and in close proximity to Eighteenmile Creek.

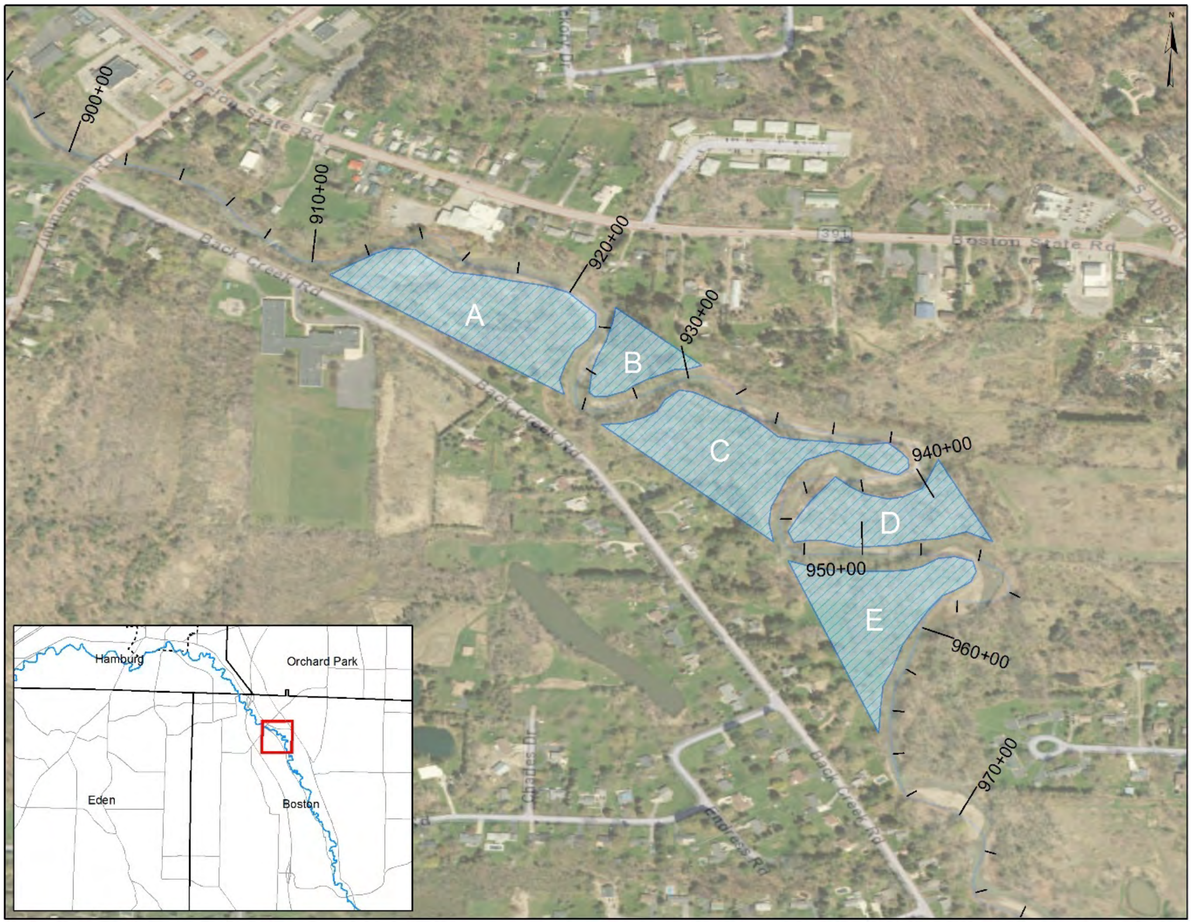

Figure 7-11. Location map for Alternative #2-3.

Table 17 is a summary of the simulations and results with river stationing, acreage, and maximum water surface elevation reductions according to model simulation results.

Table 17. Alternative #2-3 HEC-RAS flood bench and model simulation results summary

Simulation ID	River Station (ft)	Acreage (ac)	Minimum Channel Elevation (ft NAVD88)	Maximum Water Surface Reduction (ft)
Bench A	910+50 to 925+00	5.5	813	Up to 1.0-ft
Bench B	921+50 to 930+50	2.0	816	Up to 1.3-ft
Bench C	926+00 to 947+00	5.5	817	Up to 1.6-ft
Bench D	939+50 to 954+00	4.0	819	Up to 1.5-ft
Bench E	947+00 to 965+00	5.0	820	Up to 1.3-ft

The proposed condition modeling simulation confirmed that the Eckhardt Road bridge crossing is in a high-risk flood area. The model results simulated water surface reductions of up to 1.6-foot in areas adjacent to and immediately upstream of the flood benches (Figure 7-12). The modeling output for future conditions displayed similar results with water surface elevations up to 0.4-ft higher due to the increased discharges associated with predicted future flows in Eighteenmile Creek.

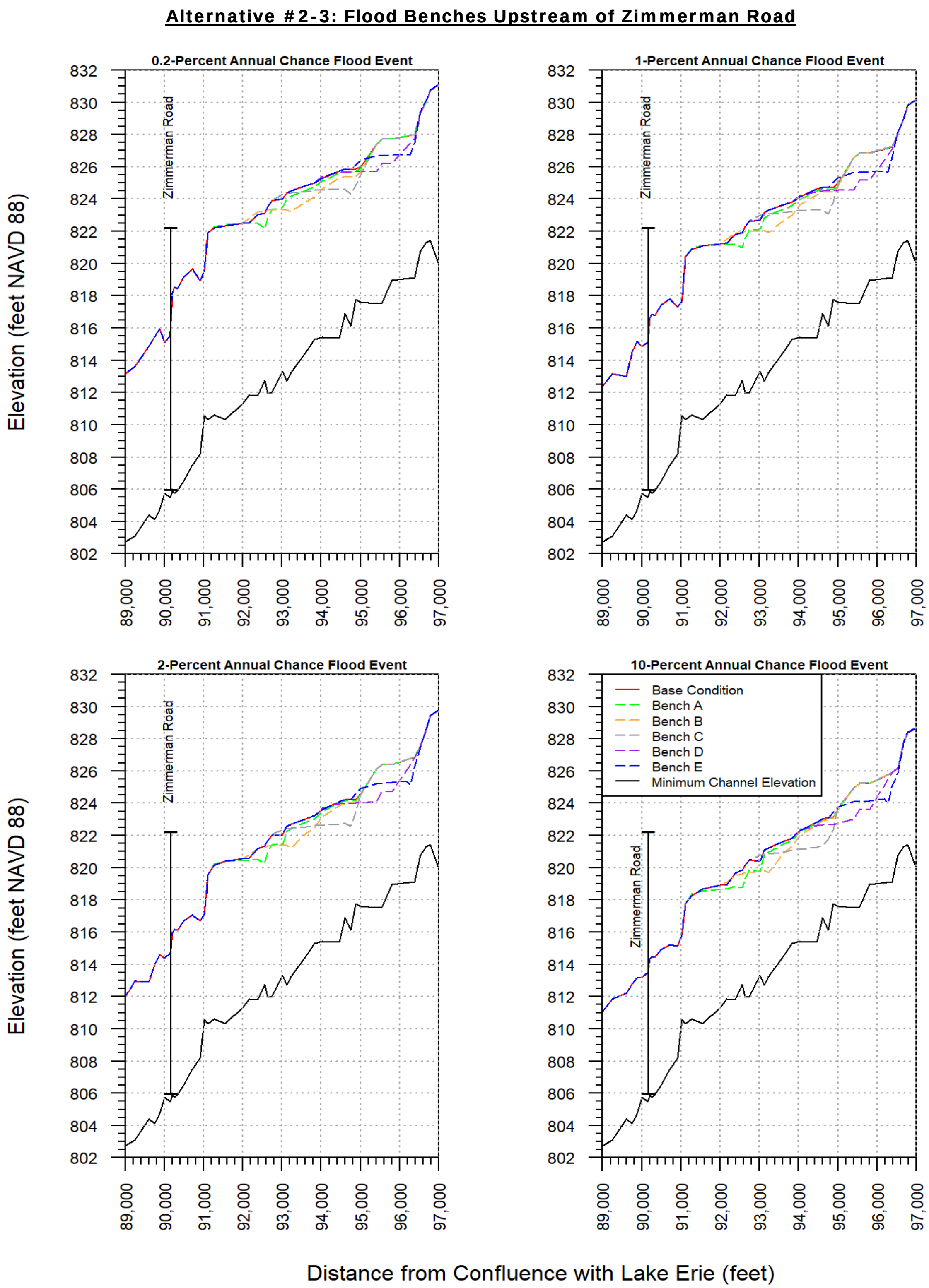

Figure 7-12. HEC-RAS model simulation output results for Alternative #2-3.

Flood benches generally provide flood protection for localized areas in the vicinity of and immediately upstream and / or downstream of the bench. Based on the analysis of high-risk areas, a flood bench located upstream of the Zimmerman Road bridge crossing would provide some protection to the properties in this reach from open-water flooding.

The potential benefits of each bench and their associated Rough Order Magnitude cost, not including land acquisition costs for survey, appraisal, and engineering coordination, are listed in Table 18.

Table 18. Alternative #2-3 potential benefits and ROM cost summary

Simulation ID	Potential Benefitted Area (ft)	ROM cost ($ U.S. dollars)
Bench A	902+50 to 947+50	$2.1 Million
Bench B	911+00 to 955+00	$2.2 Million
Bench C	917+00 to 957+00	$1.6 Million
Bench D	929+50 to 959+00	$1.9 Million
Bench E	937+50 to 965+00	$800,000

7.3 HIGH-RISK AREA #3

7.3.1 Alternative #3-1: Flood Benches in the Vicinity of Patchin Road

Installing a flood bench would provide additional storage and floodplain width, which could potentially reduce damages in the event of flooding and address issues within high-risk area #3. Five different flood benches were modeled at various locations in the vicinity of the Patchin Road bridge crossing (Figure 7-13). The total acreage of the flood benches varied from 1.5 to 6 acres. All five flood benches are located within the FEMA Regulatory Floodway or Zone AE (FEMA 2000; FEMA 2019a). Table 19 is a summary of the simulated benches characteristics and results with river stationing, acreage, minimum channel elevation, and maximum water surface elevation reductions according to model simulation results. Bench A would potentially benefit and reduce the flood risk for the May Drive neighborhood, while Benches B through E would all potentially benefit the Kevinton Place neighborhood to different extents.

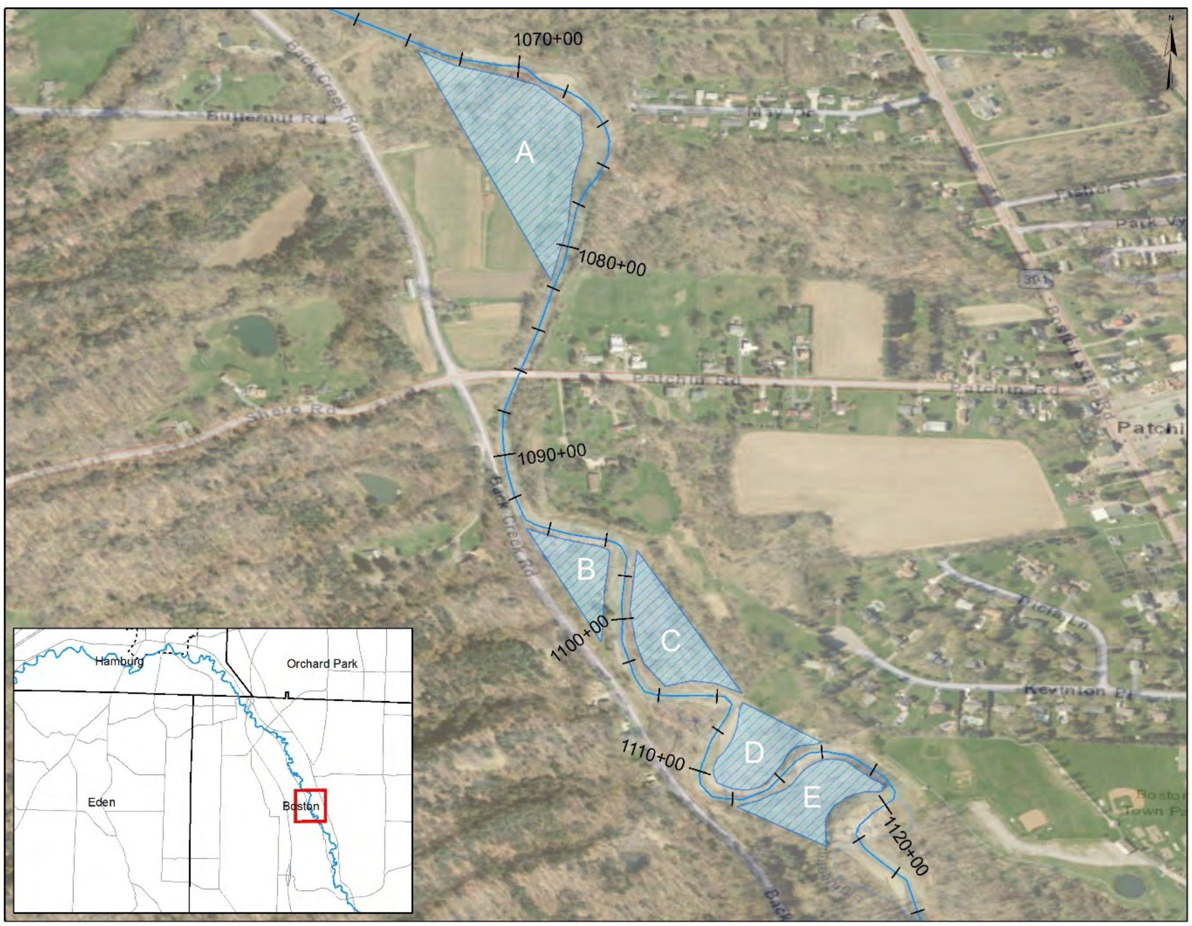

Figure 7-13. Location map for Alternative #3-1.

Table 19. Alternative #3-1 HEC-RAS flood bench and model simulation results summary

Simulation ID	River Station (ft)	Acreage (ac)	Minimum Channel Elevation (ft NAVD88)	Maximum Water Surface Reduction (ft)
Bench A	1066+00 to 1082+00	6.0	849	Up to 1.3-ft
Bench B	1093+00 to 1101+00	1.5	854	Up to 0.8-ft
Bench C	1097+00 to 1107+00	2.5	856	Up to 2.5-ft
Bench D	1107+00 to 1116+00	2.0	861	Up to 2.0-ft
Bench E	1112+00 to 1122+00	2.0	862.5	Up to 1.8-ft

The proposed condition modeling simulation confirmed that the Patchin Road bridge crossing is in a high-risk flood area. The model results simulated water surface reductions of up to 2.5-feet in areas adjacent to and immediately upstream of the flood benches (Figure 7-14). The modeling output for future conditions displayed similar results with water surface elevations up to 0.5-foot higher due to the increased discharges associated with predicted future flows in Eighteenmile Creek.

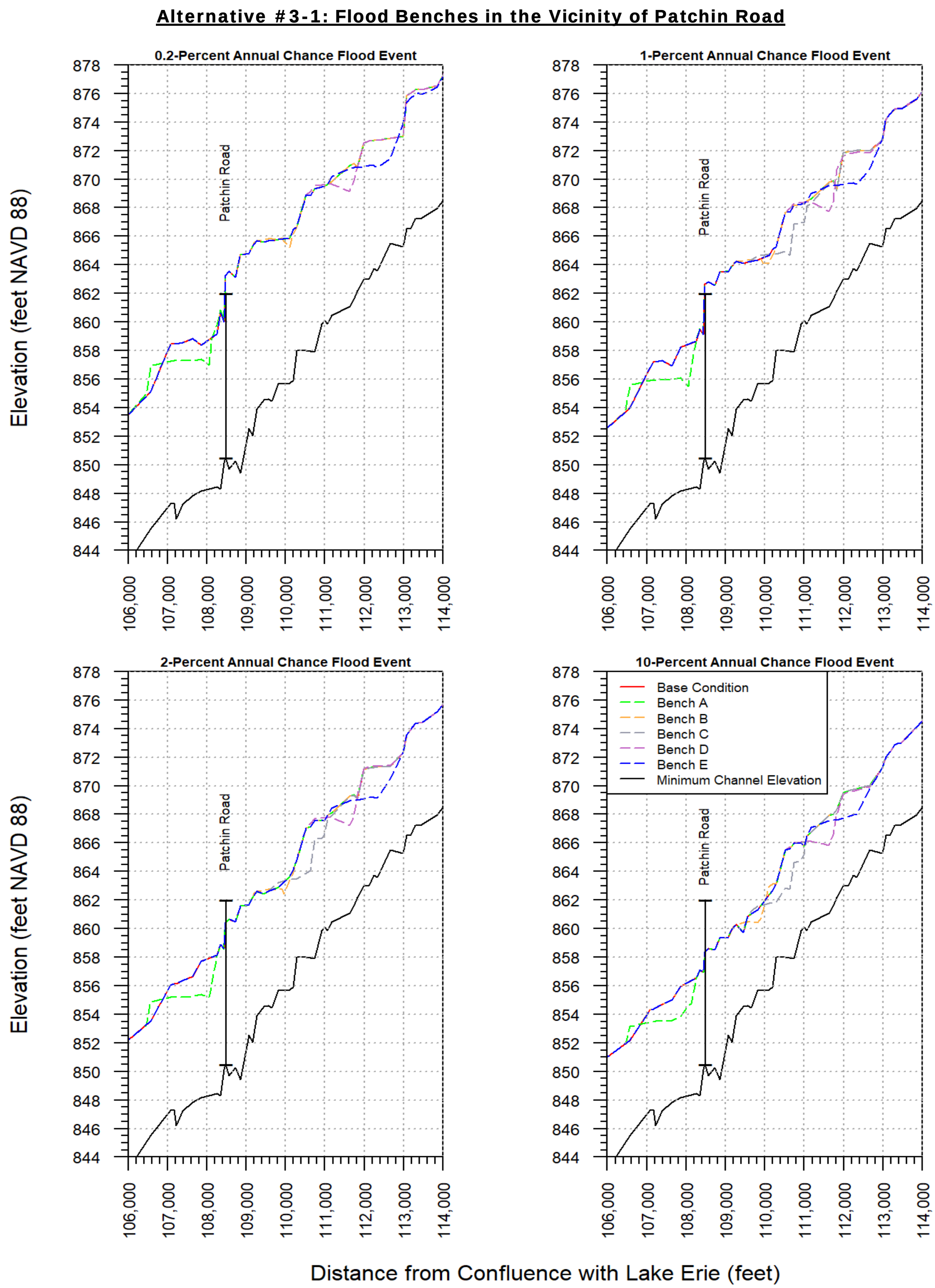

Figure 7-14. HEC-RAS model simulation output results for Alternative #3-1.

To assess the influence of ice jams on the Patchin Road bridge, an ice cover simulation with 1-foot ice thickness was performed. This simulation was intended to mimic the effects of an ice jam upstream of the bridge, which would reduce cross-sectional area and increase the in-channel roughness. The simulation was performed using Bench B due to the fact that this flood bench was the nearest upstream bench to the Patchin Road bridge crossing. When compared to existing conditions with ice cover, the simulation results indicated that for a 10-percent annual chance flood hazard event (i.e. 10-year flood) event with approximately 3,140 cfs and a 1-foot thick ice cover, water surface elevations were reduced up to 0.9-ft (Figure 7-15). However, these reductions occurred upstream of the bridge in the vicinity of Bench B. Water surfaces returned to existing ice cover condition levels downstream of the flood bench and prior to reaching Patchin Road.

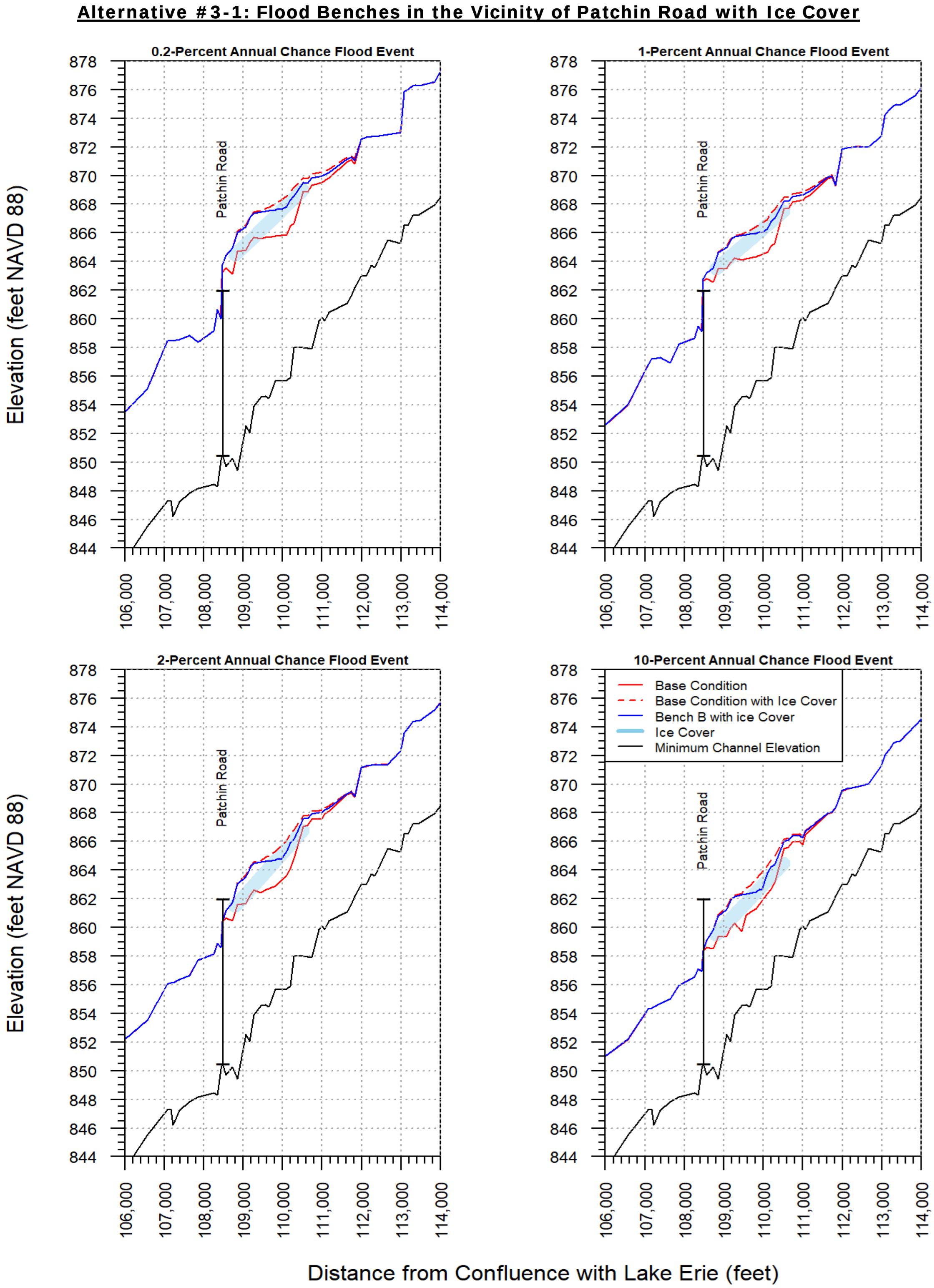

Figure 7-15. HEC-RAS ice cover model simulation output results for Alternative #3-1.

According to the HEC-RAS base, proposed, and ice condition model results, the Patchin Road bridge opening is unable to pass the 1 and 0.2-percent annual chance flood events. The FEMA FIS profile for County Road 444/Shero Road (which is the Patchin Road crossing) indicates the bridge is capable of passing all annual chance flood hazard events. The discrepancy can be explained by the difference in the discharge data used in each model simulation. The FEMA FIS used peak discharge values that were significantly lower in the upper reaches of Eighteenmile Creek when compared to the USGS *StreamStats* peak discharges. In the reach for Patchin Road, the FEMA FIS peak discharges for the 1 and 0.2-percent ACE are 3,560 and 4,140 cfs, respectively. The *StreamStats* peak discharges for the 1 and 0.2-percent ACE are 4,780 and 6,570 cfs, respectively. The percent difference for the 1 and 0.2-percent ACE are 29% and 45%, respectively. This difference in the discharge data used to calculate water surface elevations by each model explains why the HEC-RAS model simulations water surface elevations are higher since the discharge data used was significantly higher than the FEMA FIS model.

The topography of the area surrounding Patchin Road is primarily steep valley slopes. These slopes act to force surface runoff from precipitation downhill into the valley and collect in Eighteenmile Creek. As this runoff flows over the surface, erosion occurs, and sediment is collected and carried into the valley and creek channel. Based on ortho-imagery, field observations, and the stakeholder engagement meeting, sediment deposition is a significant issue in Eighteenmile Creek in the Town of Boston (NYSOITS 2017; OBG 2019; NYSDEC 2019a)

In addition, during the late winter and early spring months when ice cover forms in the creek, there is an increased potential for an ice breakup event to occur. When an ice breakup event does occur, there is the potential for ice pieces to get caught on the sediment and sand bars that have developed over time due to sediment depositional aggradation and along the abutments of the bridge as they approach the Patchin Road bridge crossing. If enough ice pieces get caught, an ice jam can form. When an ice jam is present, water flow in the channel becomes restricted, which can increase the potential for flooding upstream of the ice jam.

All of these factors act to restrict water flow in the channel, increasing the potential for open-water and ice-jam formation and backwater flooding. Flood benches generally provide flood protection for localized areas in the vicinity of and immediately upstream and / or downstream of the bench. Based on the analysis of high-risk areas, a flood bench located in the vicinity of the Patchin Road bridge crossing would provide some protection to the properties in this reach from open-water and ice-jam flooding.

The potential benefits of each bench and their associated Rough Order Magnitude cost, not including land acquisition costs for survey, appraisal, and engineering coordination, are listed in Table 20.

Table 20. Alternative #3-1 potential benefits and ROM cost summary

Simulation ID	Potential Benefitted Area (ft)	ROM cost ($ U.S. dollars)
Bench A	1060+50 to 1086+50	$2.2 Million
Bench B	1092+50 to 1104+50	$690,000
Bench C	1096+50 to 1155+50	$1 Million
Bench D	1106+50 to 1125+50	$960,000
Bench E	1111+50 to 1130+50	$980,000

7.3.2 Alternative #3-2: Widen Patchin Road Bridge

This measure is intended to address issues within High-risk Area #3 by increasing the width of the Patchin Road bridge opening, which would increase the cross-sectional flow area of the channel located at river station 1086+00 (Figure 7-16). This bridge is owned by Erie County, NY and has no piers in the channel. According to the FEMA FIRM and FIS profiles, the Patchin Road bridge low chord elevation is able to pass the 0.2% annual chance flood hazard and provides the NYSDOT recommended 2-feet of freeboard over the 2% annual chance flood water surface elevation. However, backwater occurs upstream the Patchin Road bridge, which could potentially cause backwater flooding upstream of the bridge (FEMA 2019a; FEMA 2019b). The bridge widening would potentially benefit the residential properties adjacent to and immediately upstream of Patchin Road.

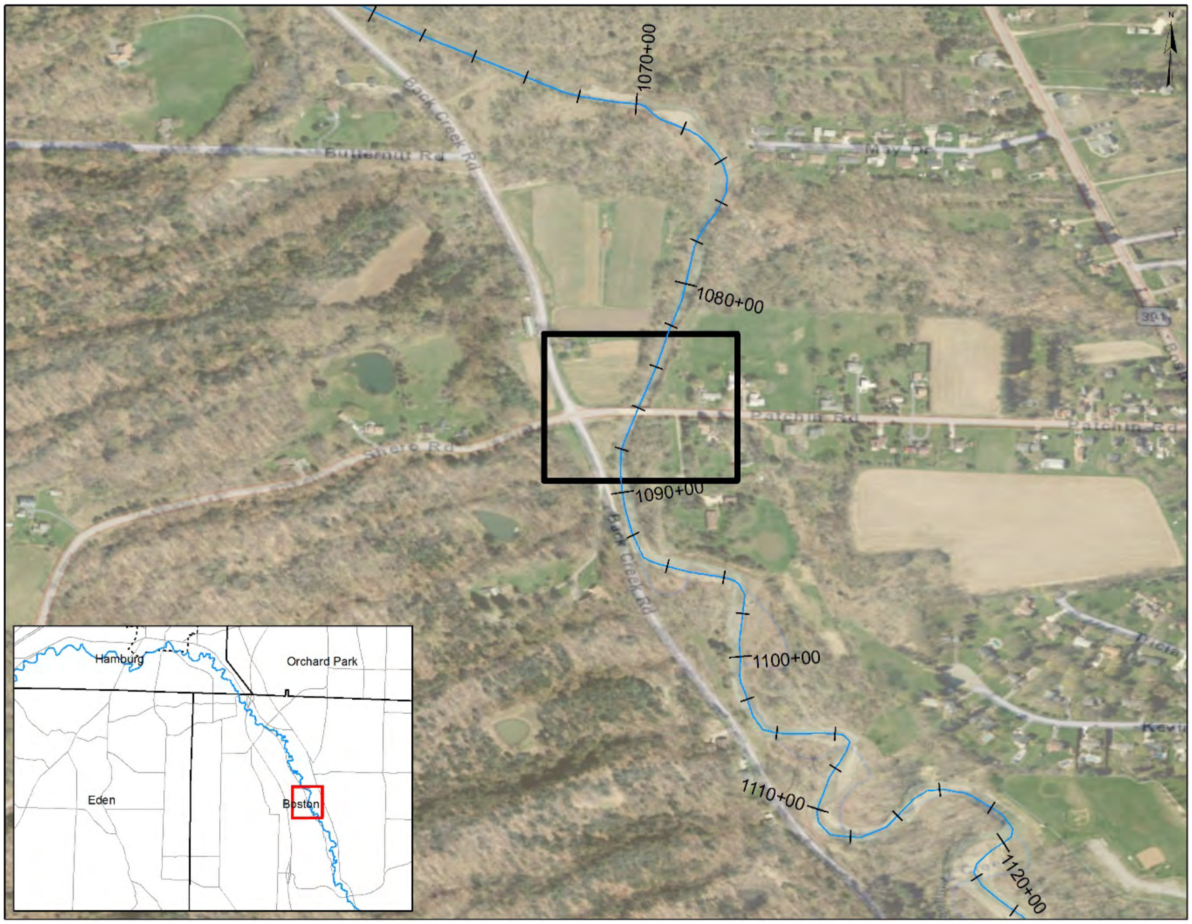

Figure 7-16. Location map for Alternative #3-2.

The proposed condition modeling confirmed that the Patchin Road bridge is a constriction point along Eighteenmile Creek. The bridge widening scenario increased the cross-sectional flow area of the bridge on both sides of the channel by approximately 33% of the current flow area, and a new bridge span of 108-feet. The model results simulated water surface reductions of up to 2.5-foot in areas adjacent to and immediately upstream of the bridge (Figure 7-17). The modeling output for future conditions displayed similar results with water surface elevations up to 2.1-feet higher due to the increased discharges associated with predicted future flows in Eighteenmile Creek.

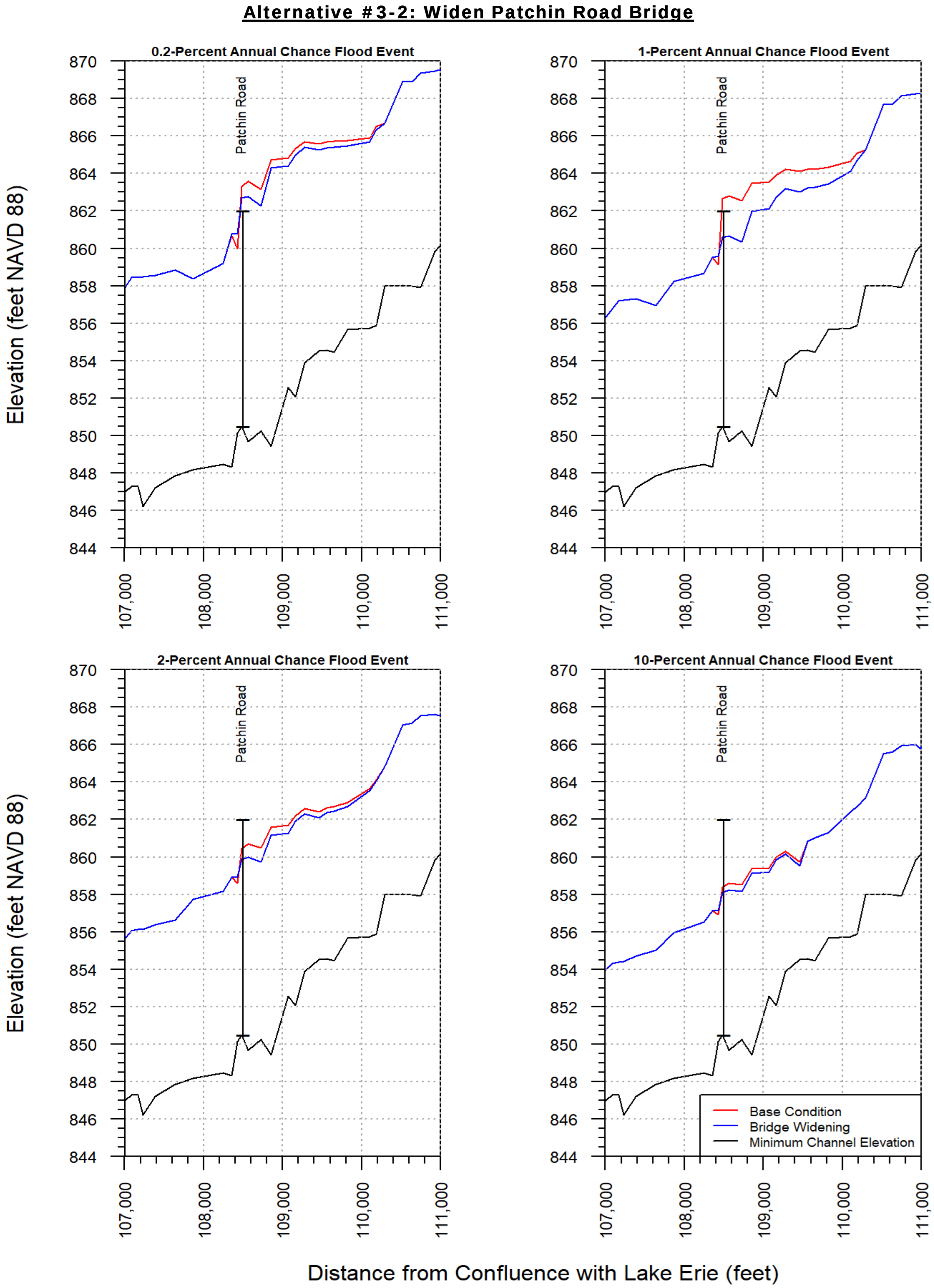

Figure 7-17. HEC-RAS model simulation output results for Alternative #3-2.

To assess the influence of ice jams on the Patchin Road bridge, an ice cover simulation with 1-foot ice thickness was performed. This simulation was intended to mimic the effects of an ice jam upstream of the bridge, which would reduce cross-sectional area and increase the in-channel roughness. When compared to existing conditions with ice cover, the simulation results indicated that for a 10% annual chance flood hazard event (i.e. 10-year flood) event with approximately 3,140 cfs and a 1-foot thick ice cover, water surface elevations reductions of up to 0.3-foot were simulated. For high flow events (i.e. less than 2% annual chance flood events), water surface elevations reductions of up to 2.0-feet were simulated immediately upstream of the bridge (Figure 7-18).

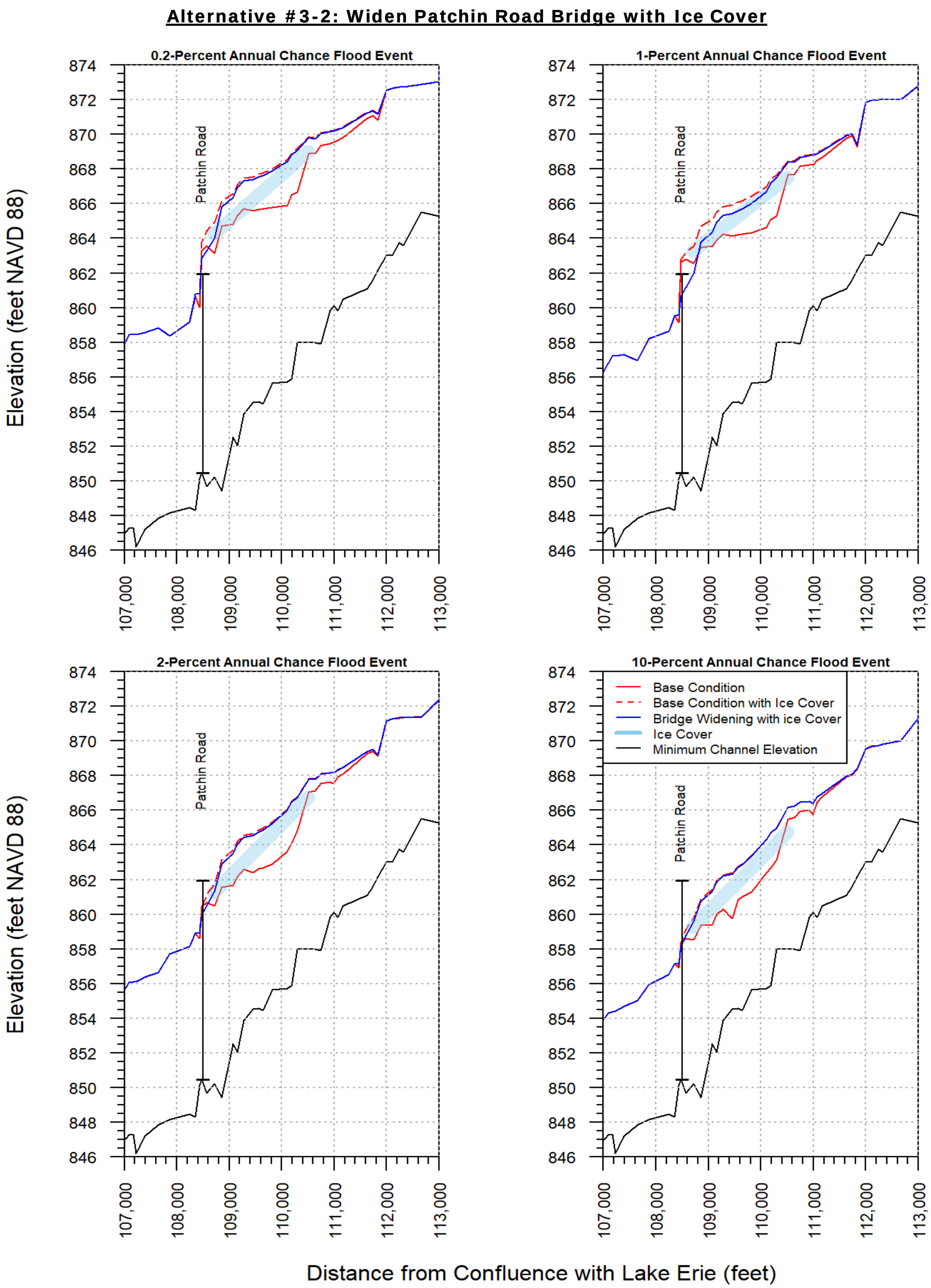

Figure 7-18. HEC-RAS ice cover model simulation output results for Alternative #3-2.

The discrepancy in the water surface elevations between the FEMA FIS and HEC-RAS model simulation results can be explained by the difference in the discharge data used in each model simulation. The FEMA FIS used peak discharge values that were significantly lower in the upper reaches of Eighteenmile Creek when compared to the USGS *StreamStats* peak discharges. This difference in the discharge data used to calculate water surface elevations by each model explains why the HEC-RAS model simulations water surface elevations are higher since the discharge data used was significantly higher than the FEMA FIS model.

Patchin Road crosses Eighteenmile Creek in the Town of Boston. Upstream of the bridge crossing, there are sediment and sand bars that have developed due to sediment depositional aggradation that restricts the in-channel flow area and causes water velocities to slow and water surfaces to rise as the flow reaches and passes under the bridge. During higher discharge events, backwater occurs upstream of the bridge increasing the potential for open water flooding. This is evidenced by the FEMA FIRM and FIS for Eighteenmile Creek at Patchin Road (County Road 444 / Shero Road) (FEMA 2019a; FEMA 2019b).

In addition, when ice cover forms in the creek upstream and an ice breakup event occurs, ice pieces can get caught on the sediment and sand bars as they approach the Patchin Road bridge and along the abutments of the bridge. All of these factors act to restrict water flow in the channel, increasing the potential for ice-jam formation and backwater flooding. In theory, widening the bridge can increase the cross-sectional area of the creek channel in the vicinity of the bridge, allowing more ice pieces and water to flow downstream and potentially reducing the risk of ice-jam formations and flooding. Based on the model simulation results, widening the Patchin Road bridge would achieve reductions in both open-water and ice-jam flooding potential.

The potential benefits of this strategy are limited to the areas in the vicinity of and immediately upstream of the Patchin Road bridge crossing, specifically between river stations 1084+00 to 1104+50.

The Rough Order Magnitude cost for this measure is $2.4 Million.

7.3.3 Alternative #3-3: Flood Benches Upstream of Hillcroft Drive

Installing a flood bench would provide additional storage and floodplain width, which could potentially reduce damages in the event of flooding and address issues within High-risk Area #3. Two different flood benches were modeled at various locations in the upstream of the Hillcroft Drive bridge crossing. The total acreage of the flood benches varied from 3 to 3.5 acres. Both flood benches are located within the FEMA Regulatory Floodway or Zone AE (FEMA 2000; FEMA 2019a). Bench A is the furthest downstream bench between river stations 1169+50 and 1180+00 with a minimum elevation of 883-ft NAVD88, and would require the excavation of 3 acres of land. Bench B is located between river stations 1178+00 and 1192+00 with a minimum elevation of 888-ft NAVD88, and would require the excavation of 3.5 acres of land (Figure 7-19). The benches would potentially benefit numerous residential and commercial properties along Boston State Road in close proximity to Eighteenmile Creek.

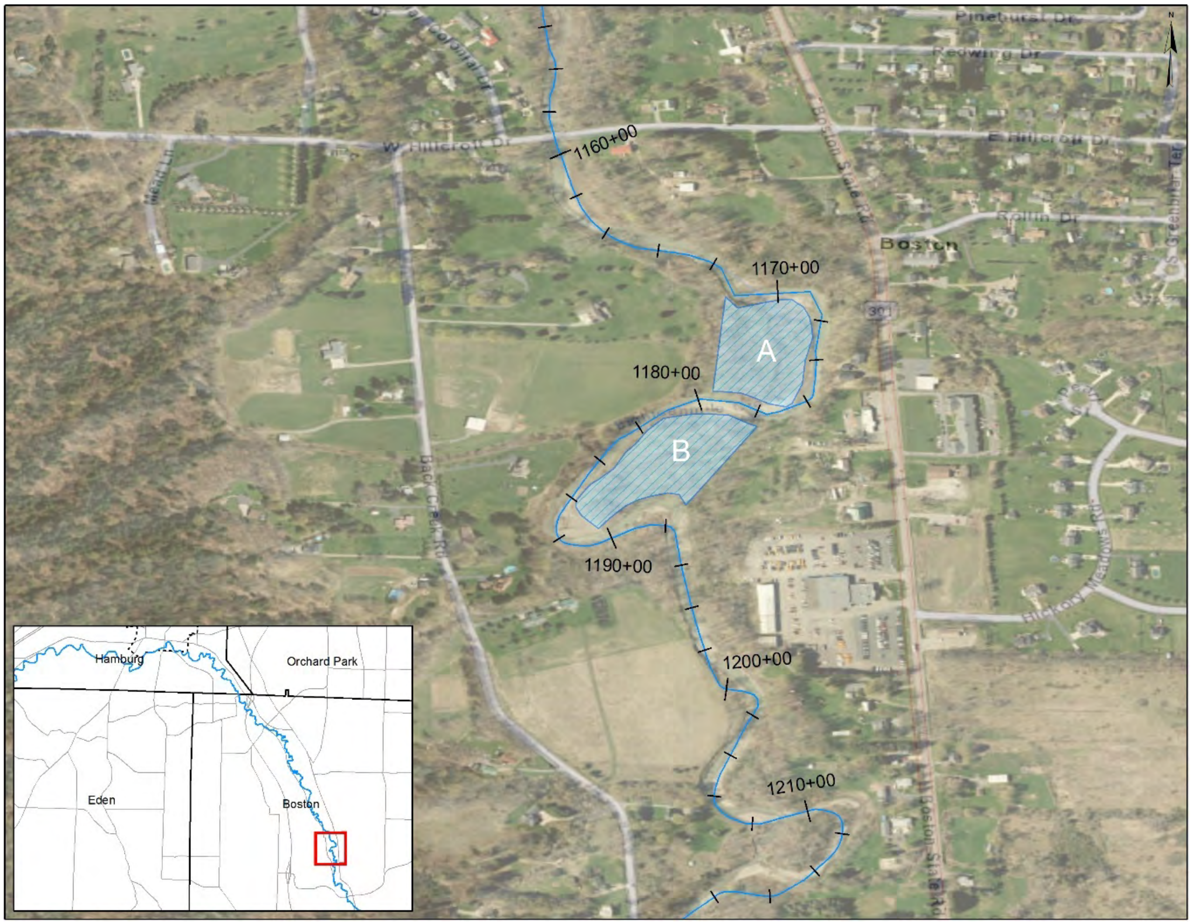

Figure 7-19. Location map for Alternative #3-3.

The proposed condition modeling simulation confirmed that the Hillcroft Drive bridge crossing is in a high-risk flood area. The model results simulated water surface reductions of up to 3.1-feet in areas adjacent to and immediately upstream of the flood benches (Figure 7-20). The modeling output for future conditions displayed similar results with water surface elevations up to 0.5-foot higher due to the increased discharges associated with predicted future flows in Eighteenmile Creek.

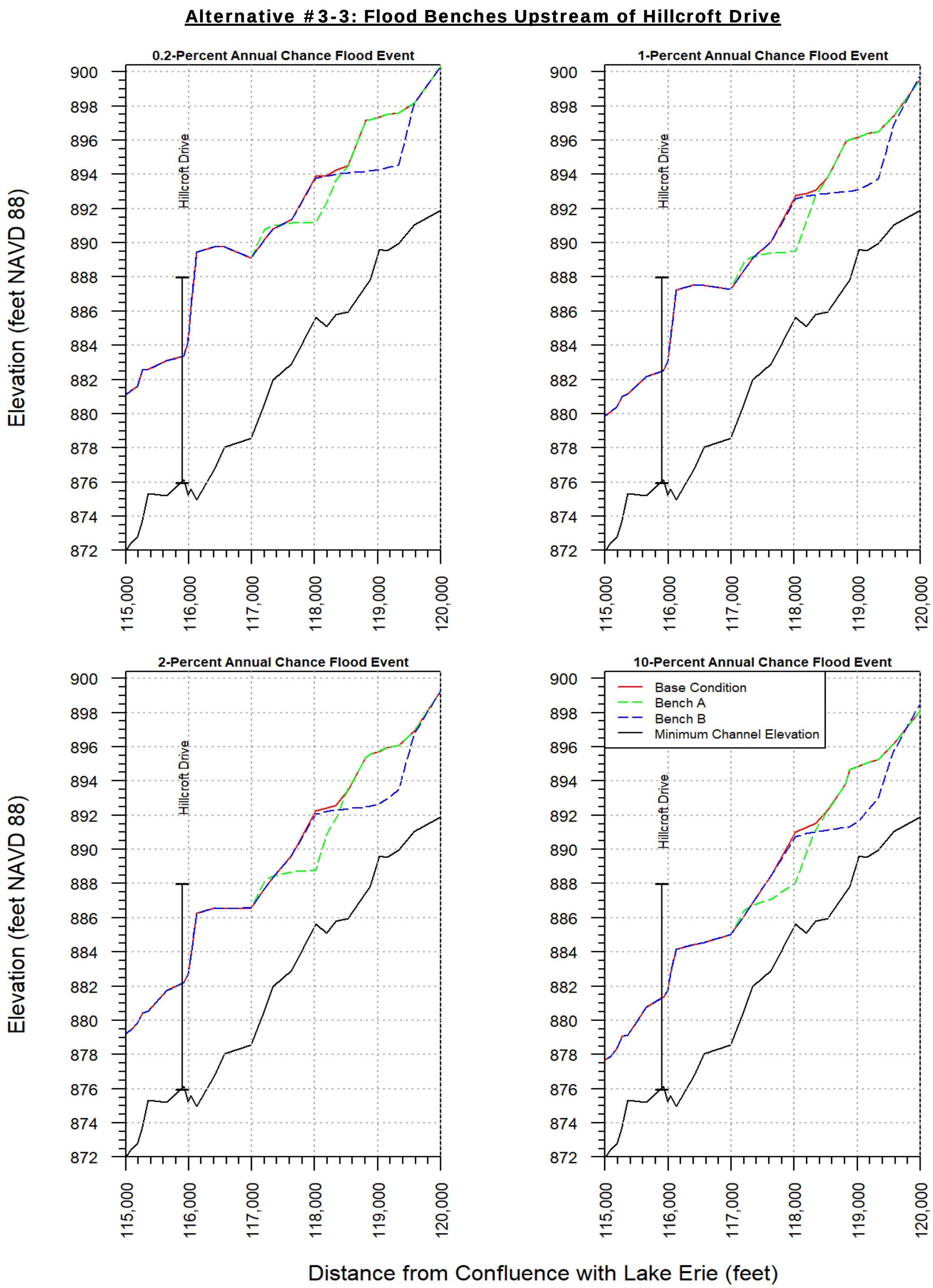

Figure 7-20. HEC-RAS model simulation output results for Alternative #3-3.

Table 21 is a summary of the simulations and results with river stationing, acreage, and maximum water surface elevation reductions according to model simulation results.

Table 21. Alternative #3-3 HEC-RAS simulation results

Simulation ID	River Station (ft)	Acreage (ac)	Maximum Water Surface Reduction (ft)
Bench A	1169+50 and 1180+00	3	Up to 2.7-ft
Bench B	1178+00 and 1192+00	3.5	Up to 3.1-ft

To assess the influence of ice jams on the Hillcroft Drive bridge, an ice cover simulation with 1-foot ice thickness was performed. This simulation was intended to mimic the effects of an ice jam upstream of the bridge, which would reduce cross-sectional area and increase the in-channel roughness. The simulation was performed using Bench A due to the fact that this flood bench was the nearest upstream bench to the Hillcroft Drive bridge crossing. When compared to existing conditions with ice cover, the simulation results indicated that for a 10% annual chance flood hazard event (i.e. 10-year flood) event with approximately 3,140 cfs and a 1-foot thick ice cover, water surface elevations were reduced up to 2.8-feet (Figure 7-21). However, these reductions occurred upstream of the bridge in the vicinity of Bench A. Water surfaces returned to existing ice cover condition levels downstream of the flood bench and prior to reaching Hillcroft Drive.

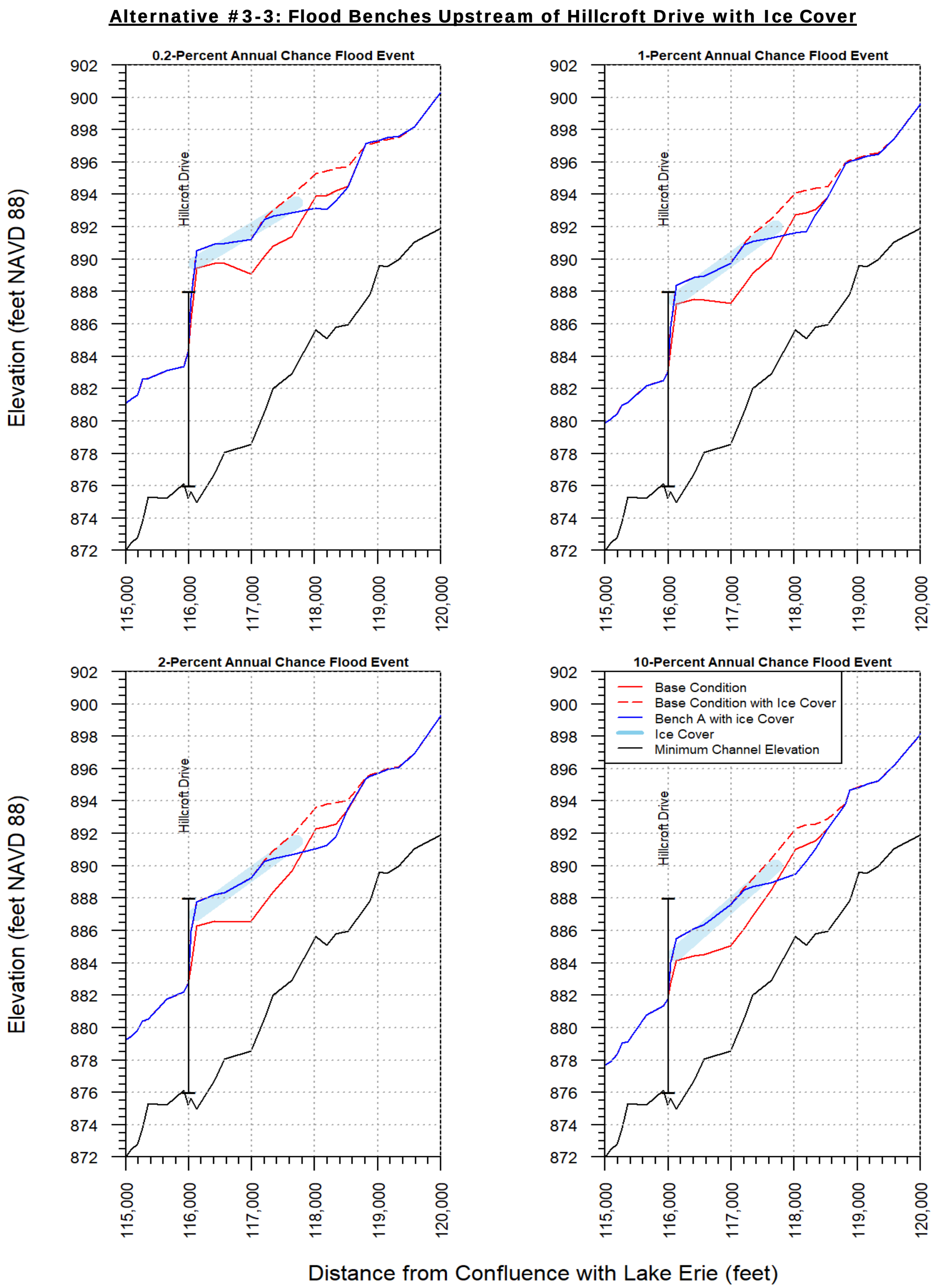

Figure 7-21. HEC-RAS ice cover model simulation output results for Alternative #3-3.

According to the HEC-RAS base, proposed, and ice condition model results, the Hillcroft Drive bridge opening is unable to pass the 0.2-percent annual chance flood events. The FEMA FIS profile for West Hillcroft Drive indicates the bridge is capable of passing all annual chance flood hazard events. The discrepancy can be explained by the difference in the discharge data used in each model simulation. The FEMA FIS used peak discharge values that were significantly lower in the upper reaches of Eighteenmile Creek when compared to the USGS *StreamStats* peak discharges. In the reach for Hillcroft Drive, the FEMA FIS peak discharges for the 0.2-percent ACE is 4,140 cfs. The *StreamStats* peak discharges for the 0.2-percent ACE 6,570 cfs. The percent difference for the 0.2-percent ACE is 45%. This difference in the discharge data used to calculate water surface elevations by each model explains why the HEC-RAS model simulations water surface elevations are higher since the discharge data used was significantly higher than the FEMA FIS model.

The topography of the area surrounding Hillcroft Drive is primarily steep valley slopes with residential and commercial properties in the floodplain. These slopes act to force surface runoff from precipitation downhill into the valley and collect in Eighteenmile Creek. As this runoff flows over the surface, erosion occurs, and sediment is collected and carried into the valley and creek channel. Based on ortho-imagery, field observations, and the stakeholder engagement meeting, sediment deposition is a significant issue in Eighteenmile Creek in the Town of Boston (NYSOITS 2017; OBG 2019; NYSDEC 2019a)

In addition, during the late winter and early spring months when ice cover forms in the creek, an ice breakup event can occur upstream of the Hillcroft Drive bridge crossing, and there is the potential ice pieces to get caught on the sediment and sand bars that have developed over time due to sediment depositional aggradation and along the abutments of the bridge as they approach the Hillcroft Drive bridge crossing. If enough ice pieces get caught, an ice jam can form. When an ice jam is present, water flow in the channel becomes restricted, which can increase the potential for flooding upstream of the ice jam.

All of these factors act to restrict water flow in the channel, increasing the potential for open-water and ice-jam formation and backwater flooding. Flood benches generally provide flood protection for localized areas in the vicinity of and immediately upstream and / or downstream of the bench. Based on the analysis of high-risk areas, a flood bench located in the vicinity of the Hillcroft Drive bridge crossing would provide some protection to the properties in this reach from open water and ice-jam flooding.

The potential benefits of each bench and their associated Rough Order Magnitude cost, not including land acquisition costs for survey, appraisal, and engineering coordination, are listed in Table 22.

Table 22. Alternative #3-3 potential benefits and ROM cost summary

Simulation ID	Potential Benefitted Area (ft)	ROM cost ($ U.S. dollars)
Bench A	1169+50 and 1189+00	$1.1 Million
Bench B	1176+00 and 1198+00	$1.3 Million

8. BASIN-WIDE MITIGATION ALTERNATIVES

Non-structural measures attempt to avoid flood damages by modifying or removing properties currently located within flood-prone areas. These measures do not affect the frequency or level of flooding within the floodplain; rather, they affect floodplain activities. In considering the range of non-structural measures, the community needs to assess the type of flooding which occurs (depth of water, velocity, duration) prior to determining which measure best suits its needs (USACE 2016b).

8.1 ALTERNATIVE #4-1: EARLY WARNING FLOOD DETECTION SYSTEM

Early warning flood detection systems can be implemented, which can provide communities with more advanced warning of potential flood conditions. Early forecast and warning involve the identification of imminent flooding, implementation of a plan to warn the public, and assistance in evacuating persons and some personal property. A typical low-cost early warning flood detection system consists of commercially available off-the-shelf-components. The major components of an early warning flood detection system are a sensor connected to a data acquisition device with built-in power supply or backup, some type of notification or warning equipment, and a means of communication.

For ice-jam warning systems, condition is generally monitored using a pressure transducer. The data acquisition system performs two functions: it collects and stores real-time flood stage data from the pressure transducer, and initiates the notification process once predetermined flood-stage conditions are met (USACE 2016b).

This method can also be supplemented by an ice-jam predicting calculation procedure using the freezing degree-day (FDD) method to forecast the ice thickness at critical locations to inform early action to control ice (Shen and Yapa 2011). The method involves a small computer tool that goes through all the ice calculations and gives the output in a graphical format of the predicted ice thickness with time. This can be quickly implemented and can be a very good solution due to its low cost, and low labor and maintenance requirements. The method needs only the forecasted air temperature and current water level at the critical location. During severe winter conditions, the ice thickness prediction can be used to help prepare and coordinate resources needed for a potential ice jam event and consequential flooding. For regular winter conditions, the tool can be used as a quick ice-thickness monitoring mechanism.

The pressure transducer system can be powered from an alternating current source via landline or by batteries that are recharged by solar panels. The notification process can incorporate standard telephone or cellular telephone. Transfer of data from the system can be achieved using standard or cellular telephone, radio frequency (RF) telemetry, wireless internet, or satellite transceivers. Emergency management notification techniques can be implemented through the use of radio, siren, individual notification, or a reverse 911 system. More elaborate means include remote sensors that detect water levels and automatically warn residents. These measures normally serve to reduce flood hazards to life, and damage to portable personal property (USACE 2016b).

The Rough Order Magnitude cost for this strategy is approximately $120,000, not including annual maintenance and operational costs.

8.2 ALTERNATIVE #4-2: DEBRIS MAINTENANCE AROUND BRIDGES / CULVERTS

Debris, such as trees, branches and stumps, are an important feature of natural and healthy stream systems. In a healthy stream network, woody debris helps to stabilize the stream and its banks, reduce sediment erosion, and slow storm-induced high streamflow events. Fallen trees and brush also form the basis for the entire aquatic ecosystem by providing food, shelter, and other benefits to fish and wildlife. In the headwaters of many streams, woody debris influences flooding events by increasing channel roughness, dissipating energy, and slowing floodwaters, which can potentially reduce flood damages in the downstream reaches. Any woody debris that does not pose a hazard to infrastructure or property should be left in place and undisturbed, thereby saving time and money for more critical work at other locations (NYSDEC 2013).

However, in some instances, significant sediment and debris can impact flows by blocking bridge and culvert openings and accumulating along the stream path at meanders, contraction / expansion points, etc., which can divert stream flow and cause backwater and bank erosion. When debris poses a risk to infrastructure, such as bridges or homes, it should be removed. Provided fallen trees, limbs, debris and trash can be pulled, cabled or otherwise removed from a stream or stream bank without significant disruption of the stream bed and banks, a permit from the NYSDEC is not required. Woody debris and trash can be removed from a stream without the need for a permit under the following guidelines:

- Fallen trees and debris may be pulled from the stream by vehicles and motorized equipment operating from the top of the streambanks using winches, chains and or cables.
- Hand-held tools, such as chainsaws, axes, handsaws, etc., may be used to cut up the debris into manageable sized pieces.
- Downed trees that are still attached to the banks should be cut off near the stump. Do not grub (pull out) tree stumps from the bank; stumps hold the bank from eroding.
- All trees, brush, and trash that is removed from the channel should not be left on the floodplain. Trash should be properly disposed of at a waste management facility. Trees and brush can be utilized as firewood. To prevent the spread of invasive species, such as Emerald Ash Borer, firewood cannot be moved more than 50 miles from its point of origin.
- Equipment may not be operated in the water, and any increase in stream turbidity from the removal must be avoided (NYSDEC 2013).

Any work that will disturb the bed or banks of a protected stream (gravel removal, stream restoration, bank stabilization, installation, repair, replacements of culverts or bridges, objects embedded in the stream that require digging out, etc.) will require an

Article 15 permit from the NYSDEC. Projects that will require disturbance of the stream bed or banks, such as excavating sand and gravel, digging embedded debris from the streambed or the use of motorized, vehicular equipment, such as a tractor, backhoe, bulldozer, log skidder, four-wheel drive truck, etc. (any heavy equipment), in the stream channel, or anywhere below the top of banks, will require either a Protection of Waters or Excavation or Fill in Navigable Waters Permit (NYSDEC 2013).

In addition, sediment control basins along Eighteenmile Creek could be established to reduce watercourse and gully erosion, trap sediment, reduce and manage runoff near and downstream of the basin, and to improve downstream water quality. A sediment control basin is an earth embankment or a combination ridge and channel generally constructed across the slope and minor watercourses to form a sediment trap and water detention basin. The basin should be configured to enhance sediment deposition by using flow deflectors, inlet and outlet selection, or by adjusting the length to width ratio of the creek channel. Additional hydrologic and hydraulic studies should be performed to identify the optimal locations for the sediment control basins. Operation and maintenance costs to maintain the embankment, design capacity, vegetative cover, and outlet of the basin should be considered (NRCS 2002).

Consultation with the NYSDEC can help determine if, when and how sediment and debris should be managed and whether a permit will be required.

The Rough Order Magnitude cost for this strategy is up to $20,000, not including annual maintenance and operational costs.

8.3 ALTERNATIVE #4-3: ICE MANAGEMENT

This strategy is intended to control ice-jam formation by maintaining ice coverage in high-risk sections of Eighteenmile Creek. Ice management strategies include various methods of preventing ice jams by breaking ice using various ice cutting patterns and techniques, as well as various equipment and personnel. Suggested locations for ice cutting operations would be provided based on anticipated effectiveness, site accessibility, and historical occurrences of ice jams. Criteria and scheduling would be provided by county and / or state agencies and determined based on environmental conditions (e.g. temperature, ice thickness, weather forecast) (USACE 2016a).

Possible ice management strategies would include:

- Ice cutting – cut ice free from banks or cross-cut ice to hasten the release of ice in order to prevent ice-jam formations
- Trenchers and special design trenching equipment – used to dig ditches customarily, but can be used to cut ice to hasten release downstream
- Channeling plow – plow mounted to a sledge drawn by a tractor that breaks and clears ice from channel
- Water jet and thermal cutting – supersonic water streams and thermal cutting tools to separate ice and move it downstream
- Hole cutting – drill large holes into the ice to reduce the integrity of the ice cover and curtail ice formation

- Ice breakers – ships, hovercrafts, amphibious hydraulic excavators, construction equipment, and blasting techniques designed to breakup ice and move ice downstream
- Air bubbler and flow systems – release air bubbles and warm water from the water bottom to suppress ice growth (USACE 2006)

Generally, the FDD method, as previously discussed, is a good technique to first predict the ice thickness at critical locations, such as bridges or any flow constriction structures using the forecasted air temperature. This method will let the community officers know the severity of any possible ice jams based on future air temperature, allowing for time to get equipment and labor ready for the forthcoming ice jam. A small computer program could be used to do the iterative calculations faster, so that any non-technical user can use it to foresee the ice jam (Shen and Yapa 2011).

Another technique is maintaining a calibrated ice model to predict possible ice jam locations using forecasted air temperature and flow. This will be a comprehensive 2-D river ice simulation model (RICEN) (Shen et al. 1995) or Comprehensive River Ice Simulation System (CRISSP 2D) (CEATI 2005) that predicts the fate of ice evolution from fall to spring.

The Rough Order Magnitude cost for this measure is $40,000, not including annual maintenance and operational costs.

8.4 ALTERNATIVE #4-4: FLOOD BUYOUTS PROGRAM

Buyouts allow state and municipal agencies the ability to purchase developed properties within areas vulnerable to flooding from willing owners. Buyouts are effective management tools in response to natural disasters to reduce or eliminate future losses of vulnerable or repetitive loss properties. Buyout programs include the acquisition of private property, demolition of existing structures, and conversion of land into public space or natural buffers. The land is maintained in an undeveloped state for public use in perpetuity. Buyout programs not only assist individual homeowners, but are also intended to improve the resiliency of the entire community in the following ways (Siders 2013):

- Reduce exposure by limiting the people and infrastructure located in vulnerable areas
- Reduce future disaster response costs and flood insurance payments
- Restore natural buffers such as wetlands in order to reduce future flooding levels
- Reduce or eliminate the need to maintain and repair flood control structures
- Reduce or eliminate the need for public expenditures on emergency response, garbage collection and other municipal services in the area
- Provide open space for the community

Resilience achieved through buyouts can have real economic consequences in addition to improved social resilience. According to FEMA, voluntary buyouts cost $1 for every $2 saved in future insurance claims, an estimate which does not include money saved on flood recovery and response actions, such as local flood fighting, evacuation, and rescue, and recovery expenses that will not be incurred in the future. In order to achieve these goals, buyouts need to acquire a continuous swatch of land, rather than individual homes in isolated areas, or only some of the homes within flood-prone areas (Siders 2013).

Buyout programs can be funded through a combination of federal, state or local funds, and are generally made available following a nationally recognized disaster. FEMA administers programs to help with buyouts under the Stafford Disaster Act, and the Department of Housing and Urban Development (HUD) administers another program through Community Development Block Grants (CDBG). These funding sources can reduce the economic burden on the local community. However, these funds also come with guidelines and regulations that may constrain policy makers' options on whether to pursue a buyout strategy, and how to shape their programs. FEMA funds may be used to cover 75% of the expenses, but the remaining 25% must come from another non-federal source. In most cases, the buyout must be a cost-effective measure that will substantially reduce the risk of future flooding damage (Siders 2013).

For homes in the SFHA, FEMA has developed precalculated benefits for property acquisition and structure elevation of buildings. Based on a national analysis that derived the average benefits for acquisition and elevation projects, FEMA has determined that acquisition projects that cost $276,000 or less, or elevation projects that costs $175,000 or less, and which are located in the 1% ACE (i.e. 100 year recurrence interval) floodplain are considered cost-effective and do not require a separate benefit-cost analysis. For projects that contain multiple structures, the average cost of all structures in the project must meet the stated criteria. If the cost to acquire or elevate a structure exceeds the amount of benefits listed above, then a traditional FEMA approved benefits-cost analysis must be completed (FEMA 2015b).

In the Eighteenmile Creek watershed, there are approximately 729 residences within the FEMA 1 and 0.2% annual chance flood hazard zones. In addition, there are 3 FEMA Repetitive Loss (RL) and no Severe Repetitive Loss (SRL) properties located within the watershed (Figure 8-1) (FEMA 2019c; NYSGPO 2019).

Due to the variable nature of buyout programs, no ROM cost estimate was produced for this study. It is recommended that any buyout program begin with a cost-benefit analysis for each property. After a substantial benefit has been established, a buyout strategy study should be developed that focuses on properties closest Eighteenmile Creek in the highest-risk flood areas and progresses outwards from there to maximize flood damage reductions. In addition, structures located adjacent to flood prone infrastructure (i.e. bridges, culverts, etc.) should also be considered high-risk and prioritized in any buyout program strategy. A potential negative consequence of buyout programs is the permanent removal of properties from the floodplain, and resulting tax revenue, which would have long-term implications for local governments, and should be considered prior to implementing a buyout program.

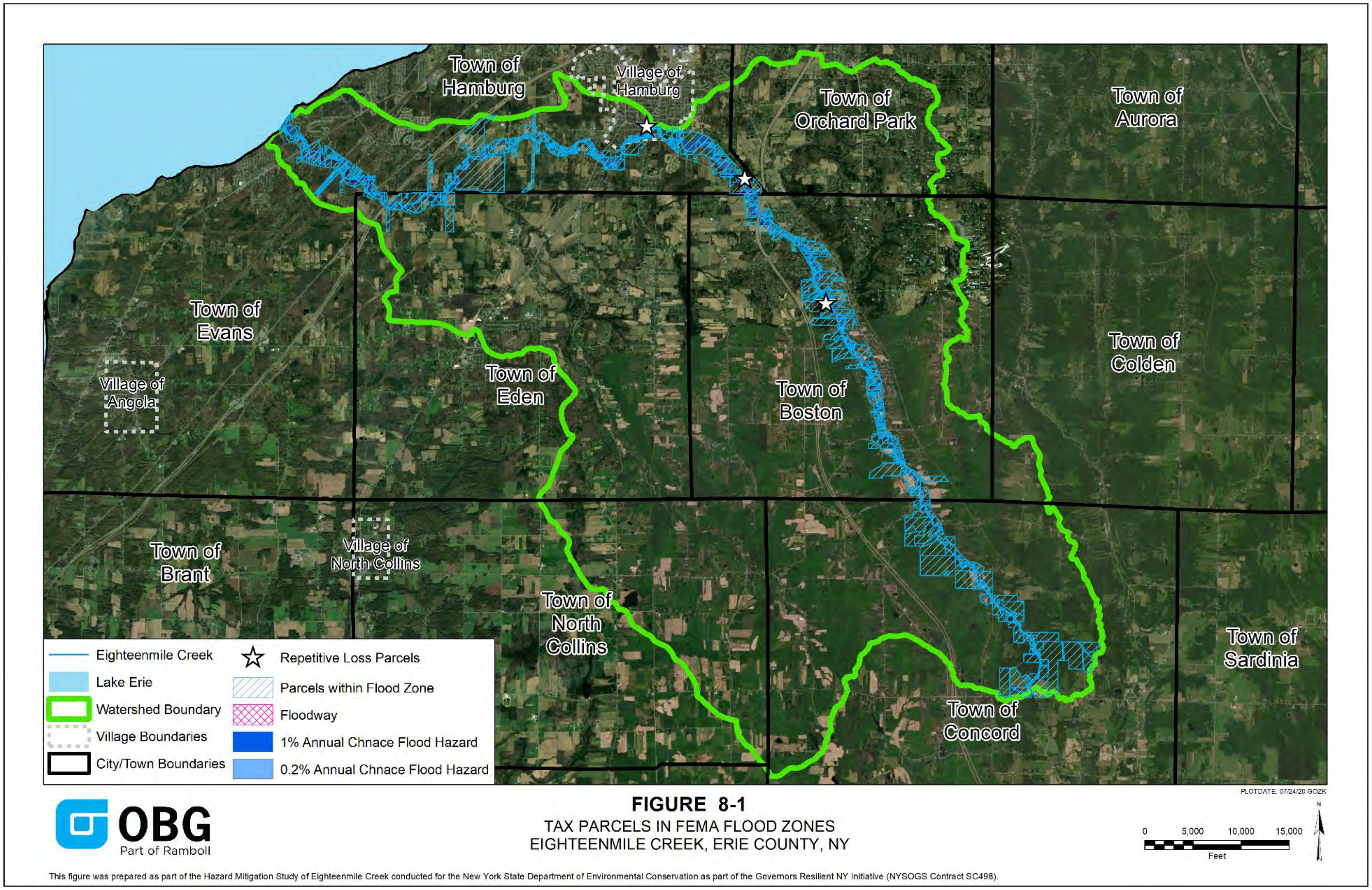

Figure 8-1. Tax parcels within FEMA flood zones, Eighteenmile Creek, Erie County, NY.

8.5 ALTERNATIVE #4-5: FLOODPROOFING

Floodproofing is defined as any combination of structural or nonstructural adjustments, changes, or actions that reduce or eliminate flood damage to a building, contents, and attendant utilities and equipment (FEMA 2000). Floodproofing can prevent damage to existing buildings and can be used to meet compliance requirements for new construction of residential and non-residential buildings.

The most effective flood mitigation methods are relocation (i.e. moving a home to higher ground outside of a high-risk flood area) and elevation (i.e. raising the entire structure above BFE). The relationship between the BFE and a structure's elevation determines the flood insurance premium. Buildings that are situated at or above the level of the BFE have lower flood risk than buildings below BFE and tend to have lower insurance premiums than buildings situated below the BFE (FEMA 2015c).

In some communities, where non-structural flood mitigation alternatives are not feasible, structural alternatives such as flood proofing may be a viable alternative. The National Flood Insurance Program has specific rules related to flood proofing for residential and non-residential structures. These can be found in the Code of Federal Regulations (CFR) 44 CFR 60.3 (FEMA 2000).

For existing residential structures, structures should be raised above the BFE in accordance with local regulations. Floodproofing is allowed for non-residential structures, with design guidelines outlined in FEMA P-936 – Floodproofing Non-Residential Structures (FEMA 2000; FEMA 2013). The local floodplain administrator should carefully review local ordinances, the CFR and available design guidelines perform issuing a permit for structural flood proofing. Floodproofing strategies include:

Interior Modification / Retrofit Measures

Interior modification and retrofitting involves making changes to an existing building to protect it from flood damage. When the mitigation is properly completed in accordance with NFIP floodplain management requirements, interior modification / retrofit measures could achieve the somewhat similar results as elevating a home above the BFE. Keep in mind, in areas where expected base flood depths are high, the flood protection techniques below may not provide protection on their own to the BFE or, where applicable, the locally required freeboard elevation (FEMA 2015c).

Examples include:

- *Basement Infill:* This measure involves filling a basement located below the BFE to grade (ground level)
- *Abandon Lowest Floor:* This measure involves abandoning the lowest floor of a two or more story slab-on-grade residential building
- *Elevate Lowest Interior Floor:* This measure involves elevating the lowest interior floor within a residential building with high ceilings

Dry floodproofing

A combination of measures that results in a structure, including the attendant utilities and equipment, being watertight with all elements substantially impermeable to the entrance of floodwater and with structural components having the capacity to resist flood loads (FEMA 2015b).

Although NFIP regulations require non-residential buildings to be watertight and protected only to the BFE for floodplain management purposes (to meet NFIP regulations), protection to a higher level is necessary for dry floodproofing measures to be considered for NFIP flood insurance rating purposes. Because of the additional risk associated with dry floodproofed buildings, to receive an insurance rating based on 1-percent annual chance (100-year) flood protection, a building must be dry floodproofed to an elevation at least 1-ft above the BFE (FEMA 2013).

In New York State, only non-residential buildings are allowed to be dry floodproofed and the building must be dry floodproofed to an elevation of at least 2 feet above the BFE. New York State has higher freeboard standards than federal regulations at 44 CFR Part 60.3. Care must be taken to check the NYS Building Code for more stringent guidelines.

Examples include:

- *Passive Dry Floodproofing System*: This measure involves installing a passive (works automatically without human assistance) dry floodproofing system around a home to protect the building from flood damage.
- *Elevation*: This measure involves raising an entire residential or non-residential building structure above BFE.

Wet floodproofing

The use of flood-damage-resistant materials and construction techniques to minimize flood damage to areas below the flood protection level of a structure, which is intentionally allowed to flood (FEMA 2015c).

Examples include:

- *Flood Openings*: This measure involves installing openings in foundation and enclosure walls located below the BFE that allow automatic entry and exit of floodwaters to prevent collapse from the pressures of standing water.
- *Elevate Building Utilities*: This measure involves elevating all building utility systems and associated equipment (e.g., furnaces, septic tanks, and electric and gas meters) to protect utilities from damage or loss of function from flooding.
- *Floodproof Building Utilities*: This measure involves floodproofing all building utility systems and associated equipment to protect it from damage or loss of function from flooding.
- *Flood Damage-Resistant Materials*: This measure involves the use of flood damage-resistant materials such as non-paper-faced gypsum board and terrazzo tile flooring for building materials and furnishings located below the BFE to reduce structural and nonstructural damage and post-flood event cleanup.

Barrier Measures

Barriers, such as floodwalls and levees, can be built around single or multiple residential and non-residential buildings to contain or control floodwaters (FEMA 2015c). Although floodwalls or levees can be used to keep floodwaters away from buildings, implementing these measures will not affect a building's flood insurance rating unless the flood control structure is accredited in accordance NFIP requirements (44 CFR §65.10) and provides protection from at least the 1% annual chance (100-year) flood. Furthermore, floodwalls or levees as a retrofit measure will not bring the building into compliance with NFIP requirements for Substantial Improvement/Damage (FEMA 2013). Barrier measures require ongoing maintenance (i.e. mowing, etc.) which should be factored into any cost analysis. In addition, barrier measures tend to create a false sense of security for the property owners and residents that are protected by them. If a barrier structure is not properly constructed or maintained and fails, catastrophic damages to surrounding areas can occur.

- *Floodwall with Gates and Floodwall without Gates*: These two measures involve installing a reinforced concrete floodwall, which works automatically without human assistance, constructed to a maximum of four feet above grade (ground level). The floodwall with gates is built with passive flood gates that are designed to open or close automatically due to the hydrostatic pressure caused by the floodwater. The floodwall without gates is built using vehicle ramps or pedestrian stairs to avoid the need for passive flood gates.
- *Levee with Gates and Levee without Gates*: These two measures involve installing an earthen levee around a home, which works automatically without human assistance, with a clay or concrete core constructed to a maximum of six feet above grade (ground level). The levee with gates is built with passive flood gates that are designed to open or close automatically due to hydrostatic pressure caused by the floodwater. The levee without gates is built using vehicle access ramps to avoid the need for passive flood gates.

Modifying a residential or non-residential building to protect it from flood damage requires extreme care, will require permits, and may also require complex, engineered designs. Therefore, the following process is recommended to ensure proper and timely completing of any floodproofing project (FEMA 2015c):

- Consult a registered design professional (i.e. architect or engineer) who is qualified to deal with the specifics of a flood mitigation project
- Check your community's floodplain management ordinances
- Contact your insurance agent to find out how your flood insurance premium may be affected
- Check what financial assistance might be available
- Hire a qualified contractor
- Contact the local building department to learn about development and permit requirements and to obtain a building permit

- Determine whether the mitigation project will trigger a Substantial Improvement declaration
- See the project through to completion
- Obtain an elevation certificate and an engineering certificate (if necessary)

No cost estimates were prepared for this alternative due to the variable and case-by-case nature of the flood mitigation strategy. Local municipal leaders should contact residential and non-residential building owners that are currently at a high flood risk to inform them about floodproofing measures, the recommended process to complete a floodproofing project, and the associated costs and benefits.

8.6 ALTERNATIVE #4-6: AREA PRESERVATION/FLOODPLAIN ORDINANCES

This alternative proposes municipalities within the Eighteenmile Creek watershed consider watershed and floodplain management practices such as preservation and/or conservation of areas along with land use ordinances that could minimize future development of sensitive areas such as wetlands, forests, riparian areas, and other open spaces. It could also include areas in the floodplain that are currently free from development and providing floodplain storage.

A watershed approach to planning and management is an important part of water protection and restoration efforts. New York State's watersheds are the basis for management, monitoring, and assessment activities. The NYS Open Space Conservation Plan, NYSDEC's Smart Growth initiative and the Climate Smart Communities Program address land use within a watershed (NYSDEC [date unknown]).

Natural floodplains provide flood risk reduction benefits by slowing runoff and storing flood water. They also provide other benefits of considerable economic, social, and environmental value that should be considered in local land-use decisions. Floodplains frequently contain wetlands and other important ecological areas which directly affect the quality of the local environment. Floodplain management is the operation of a community program of preventive and corrective measures to reduce the risk of current and future flooding, resulting in a more resilient community. These measures take a variety of forms, are carried out by multiple stakeholders with a vested interest in responsible floodplain management and generally include requirements for zoning, subdivision or building, building codes and special-purpose floodplain ordinances. While FEMA has minimum floodplain management standards for communities participating in the National Flood Insurance Program (NFIP), best practices demonstrate the adoption of higher standards which will lead to safer, stronger, and more resilient communities (FEMA 2006).

For floodplain ordinances, the NYSDEC has a sample of regulatory requirements for floodplain management that a community can adopt within their local flood damage prevention ordinance. If a community is interested in updating their local law to include regulatory language promoting floodplain management, it is recommended that they reach out to the NYSDEC through floodplain@dec.ny.gov or (518) 402-8185 for more information.

In addition, the Community Rating System (CRS) program through FEMA is a voluntary incentive program that recognizes and encourages community floodplain management activities that exceed the minimum NFIP requirements. Participating communities are able to get discounted rates on the flood insurance premiums for residents in the community. Adopting these enhanced requirements and preserving open space for floodplain storage earns points in the CRS program, which can lead to discounted flood insurance premiums.

Further hydrology and hydraulic model scenarios could be performed to illustrate how future watershed and floodplain management techniques could benefit the communities within the Eighteenmile Creek watershed.

9. NEXT STEPS

Before selecting a flood mitigation strategy, securing funding or commencing an engineering design phase, Ramboll recommends that additional modeling simulations and wetland investigations be performed.

9.1 ADDITIONAL DATA MODELING

Additional data collection and modeling would be necessary to more precisely model water surface elevations and the extent of potential flooding in overbank areas and the floodplain. 2-D unsteady flow modeling using the HEC-RAS program, would incorporate additional spatial information in model simulations producing more robust results with a higher degree of confidence than the currently modeled 1-D steady flow simulations. 2-D ice simulations are highly recommended to access the wintery condition with the suggested alternatives to evaluate the water level rises due to presence of ice, ice-jam or break-up ice jam conditions.

9.2 STATE/FEDERAL WETLANDS INVESTIGATION

Any flood mitigation strategy that proposes using wetlands in any capacity, needs to be evaluated based on federal and state wetland criteria before that mitigation strategy can be recommended for final consideration.

9.3 ICE EVALUATION

Due to the complex interaction of ice formation and water flow through a river, it is difficult to draw conclusions regarding proposed flood mitigation strategies and ice-jam formations based on observational data alone. The river bathymetry and channel meanders can complicate the ice dynamics and freeze-up jams. Spring runoff is affected by multiple environmental factors, including:

- Air temperature
- Water temperature
- Snow and ice melt intensity
- Upstream flow
- Upstream ice concentration
- Land cover
- Precipitation

Therefore, river reaches with possible or potential ice jams should be analyzed using more comprehensive ice studies, possibly a 2-D ice dynamic study, to better understand the nature of the flooding, and the necessary mitigation. Ice-jam flooding is very different compared to regular flooding due to the presence of solid and frazil ice. The transportation of frazil ice and solid ice in a river constantly changes the hydrodynamics of the flow, and even at low flows can still raise water levels high enough to cause flooding. The growth of single-layer ice jams can create conditions that change low flood hazards, to high flood hazards, even at low flow conditions.

The impact of these factors will be amplified by climate change. Projected increases in precipitation across New York State indicates the potential for increases in spring runoff, which in turn would increase water levels and velocities in nearby streams and rivers (Rosenzweig et al. 2011). In theory, the increased velocities would move solid ice and frazil ice down the river channel quicker, possibly preventing ice jam formations. However, due to the limited available research in this area, additional data collection and modeling needs to be performed before a recommendation can be made regarding a flood mitigation strategy, and its specific influence on ice jam formations.

9.4 EXAMPLE FUNDING SOURCES

There are numerous potential funding programs and grants for flood mitigation projects that may be used to offset municipal financing, including:

- NYS Division of Homeland Security and Emergency Services (NYSDHSES)
- Regional Economic Development Councils/Consolidated Funding Applications (CFA)
- Natural Resources Conservation Service (NRCS) Emergency Watershed Protection (EWP) Program
- FEMA Hazard Mitigation Assistance (HMA) Grants

9.4.1 NYS Division of Homeland Security and Emergency Services (NYSDHSES)

The NYS Division of Homeland Security and Emergency Services (NYSDHSES), through the U.S. Department of Homeland Security (DHS), offers several funding opportunities under the State Homeland Security Program (SHSP). The priority for these programs is to provide resources to strengthen national preparedness for catastrophic events. These include improvements to cybersecurity, economic recovery, housing, infrastructure systems, natural and cultural resources, and supply chain integrity and security. In 2018, there was no cost share or match requirement.

9.4.2 Regional Economic Development Councils/Consolidated Funding Applications (CFA)

The Consolidated Funding Application is a single application for state economic development resources from numerous state agencies. The ninth round of the CFA was offered in 2019. As of the writing of this report, the tenth round of CFA for 2020 was postponed due to the financial uncertainties surrounding the COVID-19 outbreak.

9.4.2.1 Water Quality Improvement Project (WQIP) Program

The Water Quality Improvement Project Program, administered through the Department of Environmental Conservation, is a statewide reimbursement grant program to address documented water quality impairments. Eligible parties include local governments and not-for-profit corporations. Funding is available for construction/implementation projects; projects exclusively for planning are not eligible. Match for WQIP is a percentage of the award amount, not the total project cost. Deadlines are in accordance with the CFA application cycle.

9.4.2.2 Climate Smart Communities (CSC) Grant Program

The Climate Smart Communities (CSC) Grant Program is a 50/50 matching grant program for municipalities under the New York State Environmental Protection Fund, offered through the CFA by the NYS Office of Climate Change. The purpose of the program is to fund climate change adaptation and mitigation projects and includes support for projects that are part of a strategy to become a Certified Climate Smart Community. The eligible project types that may be relevant include the following:

- The construction of natural resiliency measures, conservation or restoration of riparian areas and tidal marsh migration areas

  Nature-based solutions such as wetland protections to address physical climate risk due to water level rise, and/or storm surges and/or flooding

  Relocation or retrofit of facilities to address physical climate risk due to water level rise, and/or storm surges and/or flooding
- Flood risk reduction
- Climate change adaptation planning and supporting studies

Eligible projects include implementation and certification projects. Deadlines are in accordance with the CFA cycle.

9.4.3 NRCS Emergency Watershed Protection (EWP) Program

Through the Emergency Watershed Protection (EWP) Program, the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) can assist communities in addressing watershed impairments that pose imminent threats to lives and property. Most EWP projects involve the protection of threatened infrastructure from continued stream erosion. Projects must have a project sponsor, defined as a legal subdivision of the State, such as a city, county, general improvement district, or conservation district, or an Indian Tribe or Tribal organization. Sponsors are responsible for providing land rights to do repair work, securing the necessary permits, furnishing the local cost share (25 percent), and performing any necessary operation and maintenance for a ten-year period. Through EWP, the NRCS may pay up to 75 percent of the construction costs of emergency measures, with up to 90 percent paid for projects in limited-resource areas. The remaining costs must come from local services. Eligible projects include, but are not limited to, debris-clogged stream channels, undermined and unstable streambanks, and jeopardized water control structures and public infrastructures.

9.4.4 FEMA Hazard Mitigation Grant Program (HMGP)

The Federal Emergency Management Agency's Hazard Mitigation Grant Program (HMGP), offered by the New York State Division of Homeland Security and Emergency Services (NYSDHSES), provides funding for creating / updating hazard mitigation plans and implementing hazard mitigation projects. The HMA program consolidates the application process for FEMA's annual mitigation grant programs not tied to a State's Presidential disaster declaration. Funds are available under the Building Resilient

Infrastructure and Communities (BRIC) and the Flood Mitigation Assistance (FMA) Programs.

For flood mitigation measures that are being considered for funding through FEMA grant programs, a benefit-to-cost analysis will be required. In order to qualify for FEMA grants and / or funding, the benefit to cost ratio must be greater than one.

9.4.4.1 Building Resilient Infrastructure and Communities (BRIC)

Beginning in 2020, the Building Resilient Infrastructure and Communities (BRIC) grant program, which was created as part of Disaster Recovery Reform Act of 2018 (DRRA), replaced the existing Pre-Disaster Mitigation (PDM) program and is funded by a six percent set-aside from federal post-disaster grant expenditures. BRIC will support states, local communities, tribes and territories as they undertake hazard mitigation projects, reducing the risks they face from disasters and natural hazards. BRIC aims to categorically shift the federal focus away from reactive disaster spending and toward research-supported, proactive investment in community resilience. Through BRIC, FEMA will invest in a wide variety of mitigation activities, including community-wide public infrastructure projects. Moreover, FEMA anticipates BRIC will fund projects that demonstrate innovative approaches to partnerships, such as shared funding mechanisms and/or project design.

9.4.4.2 Flood Mitigation Assistance (FMA) Program

The Flood Mitigation Assistance Program provides resources to reduce or eliminate long-term risk of flood damage to structures insured under the National Flood Insurance Program (NFIP). The FMA project funding categories include Community Flood Mitigation – Advance Assistance (up to $200,000 total federal share funding) and Community Flood Mitigation Projects (up to $10 million total). Federal funding is available for up to 75 percent of the eligible activity costs. FEMA may contribute up to 100 percent federal cost share for severe repetitive loss properties, and up to 90 percent cost share for repetitive loss properties. Eligible project activities include the following:

- Infrastructure protective measures
- Floodwater storage and diversion
- Utility protective measures
- Stormwater management
- Wetland restoration/creation
- Aquifer storage and recovery
- Localized flood control to protect critical facility
- Floodplain and stream restoration
- Water and sanitary sewer system protective measures

10. SUMMARY

The Town of Boston has had a history of flooding events along Eighteenmile Creek. Flooding in the Town primarily occurs during the summer and winters months due to heavy rains by convective systems and ice jams caused by above freezing temperatures allowing ice breakups in waterways. In response to persistent flooding, the State of New York in conjunction with the Towns of Hamburg and Boston, and Erie County, are studying, addressing, and recommending potential flood mitigation projects for Eighteenmile Creek as part of the Resilient NY Initiative.

This report analyzed the historical and present day causes of flooding in the Eighteenmile Creek watershed. Hydraulic and hydrologic data was used to model potential flood mitigation measures. The model simulation results indicated that there are flood mitigation measures that have the potential to reduce water surface elevations along high-risk areas of Eighteenmile Creek, which could potentially reduce flood related damages in areas adjacent to the creek. Constructing multiple flood mitigation measures would increase the overall flood reduction potential along Eighteenmile Creek by combining the reduction potential of the mitigation measures being constructed.

Based on the flood mitigation analyses performed in this report, the mitigation measures that provided the greatest reductions in water surface elevations were the flood bench alternatives in the Town of Boston. There would be an overall greater effect in water surface elevations if multiple alternatives were built along Eighteenmile Creek in different phases, rather than a single mitigation project. For example, building multiple flood benches along a single reach would compound the flood mitigation benefits of each bench.

Based on the analysis of the bridge widening simulations, the Patchin and Eckhardt Roads bridge crossings benefited from increased bridge openings. However, the bridge widening measures are the costliest of the discussed flood mitigation measures. The benefits of the measures in their respective reaches should be balanced with the associated costs of each bridge widening measure to determine if it would be feasible to move a bridge widening measure forward. In addition, other complications, such as traffic re-routing, should be taken into account when considering any of the bridge widening measures.

The debris maintenance around culverts / bridges would maintain the flow channel area in Eighteenmile Creek. As sediment and debris build up at the openings of bridges and culverts, the channel flow area is reduced. This can lead to potential backwater and flooding due to the inability of the creek channel to pass stream flows of the same annual chance event.

Ice management to control ice buildup at critical points along Eighteenmile Creek would be highly recommended for areas upstream of known flood-prone zones. An ice prediction method using the FDD would be a good starting point to monitor and mitigate any ice related flooding before it actually occurs. For example, planning, preparation, equipment and labor management for ice break-up using amphibious excavators is highly effective at preventing ice jams and potential flooding at key infrastructure points. Therefore, good prediction of possible ice jams enables municipalities to have the appropriate equipment available at the right time and place. This will reduce indirect costs and inconvenience. To alleviate costs of equipment purchase, operation, and maintenance, the County and local Townships could share ownership. Recurring maintenance and staffing required in order to operate the equipment should be factored into any cost analysis.

For flood mitigation measures that are being considered for funding through FEMA grant programs, a benefit-to-cost analysis will be required. In order to qualify for FEMA grants and / or funding, the benefit to cost ratio must be greater than one. Flood buyouts / property acquisitions can qualify for FEMA grant programs with a 75% match of funds. The remaining 25% of funds is the responsibility of state, county, and local governments. The case-by-case nature of buyouts and acquisitions requires widespread property owner participation to maximize flood risk reductions. An unintended consequence of buyout programs is the permanent removal of properties from the floodplain, including tax revenue, which would have long-term implications for local governments and should be considered prior to implementing a buyout program.

Floodproofing is an effective mitigation measure but requires a large financial investment in individual residential and non-residential buildings. Floodproofing can reduce the future risk and flood damage potential but leaves buildings in flood risk areas so that future flood damages remain. A benefit to floodproofing versus buyouts is that properties remain in the Village and the tax base for the local municipality remains intact. Table 23 is a summary of the proposed flood mitigation measures, including modeled water surface elevation reductions and estimated ROM costs.

Table 23. Summary of Flood Mitigation Measures

Alternative No.	Description	Change in Water Surface Elevation (ft)	ROM cost ($U.S. dollars)
1-1	Flood Benches Upstream of Eckhardt Road	Up to 1.5-ft	$1.8 – 2.1 Million
1-2	Widen Eckhardt Road Bridge	Up to 0.5-ft	$2.8 Million
2-1	Flood Benches Downstream of Zimmerman Road	Up to 1.7-ft	$930,000 – 2.4 Million
2-2	Widen Zimmerman Road Bridge	Up to 0.2-ft	$3 Million
2-3	Flood Benches Upstream of Zimmerman Road	Up to 1.6-ft	$800,000 – $2.2 Million
3-1	Flood Benches in the Vicinity of Patchin Road	Up to 2.5-ft	$690,000 - $2.2 Million
3-2	Widen Patchin Road Bridge	Up to 2.1-ft	$2.4 Million
3-3	Flood Benches Upstream of Hillcroft Drive	Up to 3.1-ft	$1.1 – 1.3 Million
4-1	Early Warning Flood Detection System	N/A	$120,000 (not including annual operational costs)
4-2	Debris Maintenance Around Culverts / Bridges	N/A	$20,000 (not including annual operational costs)
4-3	Ice Management	N/A	$40,000 (not including annual operational costs)
4-4	Flood Buyouts / Property Acquisitions	N/A	Variable (case-by-case)
4-5	Floodproofing	N/A	Variable (case-by-case)
4-6	Area Preservation / Floodplain Ordinances	N/A	Variable (case-by-case)

11. CONCLUSION

Municipalities affected by flooding along Eighteenmile Creek can use this report to support flood mitigation initiatives within their communities. This report is intended to be a high-level overview of proposed flood mitigation strategies and their potential impacts on water surface elevations in Eighteenmile Creek. The research and analysis that went into each proposed strategy should be considered preliminary, and additional research, field observations, and modeling are recommended before final mitigation strategies are chosen.

In order to implement the flood mitigation strategies proposed in this report, communities should engage in a process that follows the following steps:

1. Obtain stakeholder and public input to assess the feasibility and public support of each mitigation strategy presented in this report.
2. Complete additional data collection and modeling efforts to assess the effectiveness of the proposed flood mitigation strategies.
3. Develop a list of final flood mitigation strategies based on the additional data collection and modeling results.
4. Select a final flood mitigation strategy or series of strategies to be completed for Eighteenmile Creek based on feasibility, permitting, effectiveness, and available funding.
5. Develop a preliminary engineering design report and cost estimate for each selected mitigation strategy.
6. Assess funding sources for the selected flood mitigation strategy.

Once funding has been secured and the engineering design has been completed for the final mitigation strategy, construction and / or implementation of the measure should begin.

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APPENDICES

APPENDIX A
SUMMARY OF DATA AND REPORTS COLLECTED

Appendix A. Summary of Data and Reports Collected			NYSOGS Project # SC498
Resilient New York Flood Mitigation Initiative			**OBG Project # SC807**
Eighteenmile Creek – Erie County, New York			**19-Oct-20**
Year	**Type**	**Title**	**Author**
2008	Data	Erie County, NY - LiDAR Terrain Elevation	New York State Department of Environmental Conservation (NYSDEC)
2008	Data	Preliminary integrated geologic map databases for the United States: Delaware, Maryland, New York, Pennsylvania, and Virginia, Version 1.1.	United States Geologic Service (USGS)
2014	Data	National Register of Historic Places	National Park Service (NPS)
2017	Data	NYS Digital Ortho-imagery Program (NYSDOP) - 2017 Imagery in Erie County	New York State Office of Information Technology Services
2019	Data	Bridges, Streets, Railroads	New York State Department of Transportation (NYSDOT)
2019	Data	City/Town Boundaries, County Boundaries	New York State Office of Information Technology Services (NYSOITS)
2019	Data	Dams, Hydrography	New York State Department of Environmental Conservation (NYSDEC)
2019	Data	Flood Insurance Rate Map (FIRM), Erie County, NY	Federal Emergency Management Agency (FEMA)
2019	Data	National Flood Hazard Layer, Erie County, NY	Federal Emergency Management Agency (FEMA)
2019	Data	National Land Cover Database (NLCD)	Multi-Resolution Land Characteristics (MRLC) consortium
2019	Data	New York Cropland Data Layer	United States Department of Agriculture (USDA)
2019	Data	Tax Parcels	New York State Office of Information Technology Services GIS Program Office, New York State Department of Taxation and Finance's Office of Real Property Tax Services (ORPTS), Erie County Real Property Tax Services (ECRPTS)
2020	Data	Ice Jam Database	Cold Regions Research and Engineering Laboratory (CRREL)
2020	Data	Repetitve Loss and Severe Repetitive Loss Properties	Federal Emergency Management Agency (FEMA)
2020	Data	Storm Events Database	National Centers for Environmental Information (NCEI)
1978	Report	The Southern Expressway North Boston to Springville, Erie County Including an Overview of US 219 from Interstate 90 to the Vicinity of Salamanca	Federal Highway Administration (FHA)
1981	Report	Flood Insurance Study Town of Boston, New York, Erie County	Federal Insurance Administration (FIA)
1981	Report	Flood Insurance Study Village of Hamburg, New York, Erie County	Federal Emergency Management Agency (FEMA)
1986	Report	Soil Survey of Erie County, New York	United States Geologic Service (USGS)

1991	Report	Regionalization of flood discharges for rural, unregulated streams in New York, excluding Long Island	United States Geologic Service (USGS)
2000	Report	Title 44. Emergency Management and Assistance Chapter I. Federal Emergency Management Agency, Department of Homeland Security Subchapter B. Insurance and Hazard Mitigation	Federal Emergency Management Agency (FEMA)
2001	Report	Environmental Considerations for Vegetation in Flood Control Channels	United States Army Corps of Engineers (USACE)
2001	Report	Flood Insurance Study Town of Hamburg, New York, Erie County	Federal Emergency Management Agency (FEMA)
2005	Report	Erie County All-Hazard Mitigation Plan	Erie County Division of Civil Defense & Disaster Preparedness (DCDDP)
2006	Report	Bridge Inventory Manual (2006 Edition)	New York State Department of Transportation (NYSDOT)
2006	Report	Engineering and Design - ICE ENGINEERING	United States Army Corps of Engineers (USACE)
2006	Report	Magnitude and Frequency of Floods in New York	United States Geologic Service (USGS)
2009	Report	Bankfull discharge and channel characteristics of streams in New York State	United States Geologic Service (USGS)
2011	Report	Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation	New York State Energy Research and Development Authority (NYSERDA)
2013	Report	Floodproofing Non-Residential Buildings	Federal Emergency Management Agency (FEMA)
2015	Report	Development of flood regressions and climate change scenarios to explore estimates of future peak flows	United States Geologic Service (USGS)
2015	Report	Reducing Flood Risk to Residential Buildings That Cannot Be Elevated	Federal Emergency Management Agency (FEMA)
2016	Report	NYSDOT LRFD Bridge Design Specifications	New York State Department of Transportation (NYSDOT)
2018	Report	New York State Flood Risk Management Guidance for Implementation of the Community Risk and Resiliency Act [DRAFT]	New York State Department of Environmental Conservation (NYSDEC)
2019	Report	Bridge Manual	New York State Department of Transportation (NYSDOT)
2019	Report	Flood Insurance Study (FIS), Erie County, NY	Federal Emergency Management Agency (FEMA)
2016	Software	Application of Flood Regressions and Climate Change Scenarios to Explore Estimates of Future Peak Flows - Future Flow Explorer v1.5	United States Geologic Service (USGS)
2016	Software	Functional Class Viewer	New York State Department of Transportation (NYSDOT)
2017	Software	National Climate Change Viewer	United States Geologic Service (USGS)
2019	Software	ArcGIS Desktop 10.7.1	Environmental Systems Research Institute (ESRI)
2019	Software	HEC-RAS 5.0.7	United States Army Corps of Engineers (USACE), Hydrologic Engineering Center (HEC)
2019	Software	RSMeans Cost Works 2019 v16.03	Gordian, Inc.
2019	Software	StreamStats v4.3.11	United States Geologic Service (USGS)

2019	Software	Web Soil Survey 3.3	United States Department of Agriculture (USDA)
2020	Software	Environmental Resource Mapper	New York State Department of Environmental Conservation (NYSDEC)
2020	Software	Information for Planning and Consultation (IPaC)	United States Fish and Wildlife Service (USFWS)

APPENDIX B

FIELD DATA COLLECTION FORM EXAMPLES

Stream Channel Classification (Level II)

Wisconsin Job Sheet 811

Natural Resources Conservation Service (NRCS) **Wisconsin**

Project: ______________________________ Date: ______________________________

County: ______________________________ Stream: ______________________________

Reach No.: ______________________________ Logged By: ______________________________

Horizontal Datum: NAD ________ Projection: ☐Transverse Mercator ☐Lambert Conformal Conical

Coordinate System: ☐ __________ County Coordinates ☐WTM ☐State Plane Coordinates ☐UTM

Units: ☐Meters ☐Feet Horizontal Control: N or Lat. ____________ E or Long. ____________

Elevation: _____________ ☐Assumed ☐DOT ☐NAVD (29 / 88) Units: ☐Meters ☐Feet

Fluvial Geomorphology Features (3 Cross Sections) for Stream Classification

				Average
Bankfull Width (W_{bkf}):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

Width of the stream channel, at bankfull stage elevation, in a riffle section.

Mean Depth (d_{bkf}):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

Mean depth of the stream channel cross section, at bankfull stage elevation, in a riffle section. ($d_{bkf}=A_{bkf}/W_{bkf}$)

Bankfull X-Section Area (A_{bkf}):	_________ sq. ft.	_________ sq. ft.	_________ sq. ft.	0.00 sq. ft.

Area of the stream channel cross section, at bankfull stage elevation, in a riffle section.

Width / Depth Ratio (W_{bkf}/d_{bkf}):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

Bankfull width divided by bankfull mean depth, in a riffle section.

Maximum Depth (d_{mbkf}):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

Maximum depth of the Bankfull channel cross section, or distance between the bankfull stage and thalweg elevations, in a riffle section.

Width of Flood-Prone Area (W_{fpa}):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

Twice maximum depth, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area width is determined (riffle section).

Entrenchment Ratio (ER):	_________ ft.	_________ ft.	_________ ft.	0.00 ft.

The ratio of flood-prone area width divided by bankfull channel width. (W_{fpa}/W_{bdf}) (riffle section)

Reach Characteristics

Channel Materials (Particle Size Index) D50: _________ mm

The D50 particle size index represents the median diameter of channel materials, as sampled from the channel surface, between the bankfull stage and thalweg elevations.

Water Surface Slope (S): ________________ ft./ft.

Channel slope = "rise" over "run" for a reach approximately 20-30 bankfull channel widths in length, with the "riffle to riffle" water surface slope representing the gradient at bankfull stage.

Channel Sinuosity (K): ________________.

Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL/VL); or estimated from a ratio of valley slope divided by channel slope (VS/S).

Distance to Up-Stream Structures: _____________________________.

Stream Type: _____________________ (For reference, note Stream Type Chart and Classification Key)

Dominant Channel Soils at an Eroding Bank Location

Bed Material: __________________________ Left Bank: ___________ Right Bank: ___________

Description of Soil Profiles (from base of bank to top):

Left: ____

____

Right: ____

____

Riparian Vegetation at an Eroding Bank Location

Left Bank: _____________________________ Right Bank: ____________________________

Percent Total Area (Mass): Left: __________________ Right: ___________________________

Percent Total Height with Roots: Left: __________________ Right: ______________________

Other Bank Features at an Eroding Bank Location

Actual Bank Height: _______________________ Bankfull Height: _________________________

Bank Slope (Horizontal to Vertical):

Left:
- ☐ 0-20º (flat)
- ☐ 21-60º (moderate)
- ☐ 61-80º (steep)
- ☐ 81-90º (vertical)
- ☐ 90º+ (undercut)

Right:
- ☐ 0-20º (flat)
- ☐ 21-60º (moderate)
- ☐ 61-80º (steep)
- ☐ 81-90º (vertical)
- ☐ 90º+ (undercut)

Visible Seepage in Bank? ☐ Yes ☐ No Where? _________________________________

Thalweg Location: ☐ Near 1/3 ☐ Mid 1/3 ☐ Far 1/3

Pebble Count (Data Collection)

Wisconsin Job Sheet 810

U.S. Department of Agriculture
Natural Resources Conservation Service

Natural Resources Conservation Service (NRCS) **Wisconsin**

Project: ______________________ Date: ______________________

County: ______________________ Stream: ______________________

Reach No.: ______________________ Logged By: ______________________

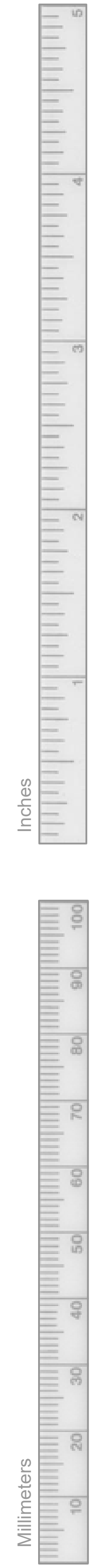
Horizontal Datum: NAD ________ Projection: ☐Transverse Mercator ☐Lambert Conformal Conical

Coordinate System: ☐ __________ County Coordinates ☐WTM ☐State Plane Coordinates ☐UTM

Units: ☐Meters ☐Feet Horizontal Control: N or Lat. __________ E or Long. __________

Elevation: __________ ☐Assumed ☐DOT ☐NAVD (29 / 88) Units: ☐Meters ☐Feet

Inches	Millimeters	Particle	Particle Count 1	Total #	Particle Count 2	Total #
<.002	<.062	Silt/Clay				
.002 - .005	.062 - .125	Very Fine Sand				
.005 - .01	.125 - .25	Fine Sand				
.01 - .02	.25 - .50	Medium Sand				
.02 - .04	.50 - 1.0	Coarse Sand				
.04 - .08	1.0 - 2	Very Coarse Sand				
.08 - .16	2 - 4	Very Fine Gravel				
.16 - .22	4 - 5.7	Fine Gravel				
.22 - .31	5.7 - 8	Fine Gravel				
.31 - .44	8 - 11.3	Medium Gravel				
.44 - .63	11.3 - 16	Medium Gravel				
.63 - .89	16 - 22.6	Coarse Gravel				
.89 - 1.26	22.6 - 32	Coarse Gravel				
1.26 - 1.77	32 - 45	Very Coarse Gravel				
1.77 - 2.5	45 - 64	Very Coarse Gravel				
2.5 - 3.5	64 - 90	Small Cobbles				
3.5 - 5.0	90 - 128	Small Cobbles				
5.0 - 7.1	128 - 180	Large Cobbles				
7.1 - 10.1	180 - 256	Large Cobbles				
10.1 - 14.3	256 - 362	Small Boulders				
14.3 - 20	362 - 512	Small Boulders				
20 - 40	512 - 1024	Medium Boulders				
40 - 80	1024 - 2048	Large-Very Large Boulders				
		Bedrock				



Field Observation Form

By:______________________ Date: ____________________ Project Name: _________________________________
Project Number: _______________________________

Location/Description

____

____

____

____

____

Sketches (Include flow depth, channel bed material, Manning values, flow direction, etc.)

Plan View:

Section View:

Structure Data

☐ Bridge ☐ Culvert

Height: _____________ Width: ____________ ☐ Box # Sides: _____ ☐ Pipe ☐ Arch ☐ Other

Length in direction of flow: _______________ Manning Value Top: ____________ Bottom: _____________

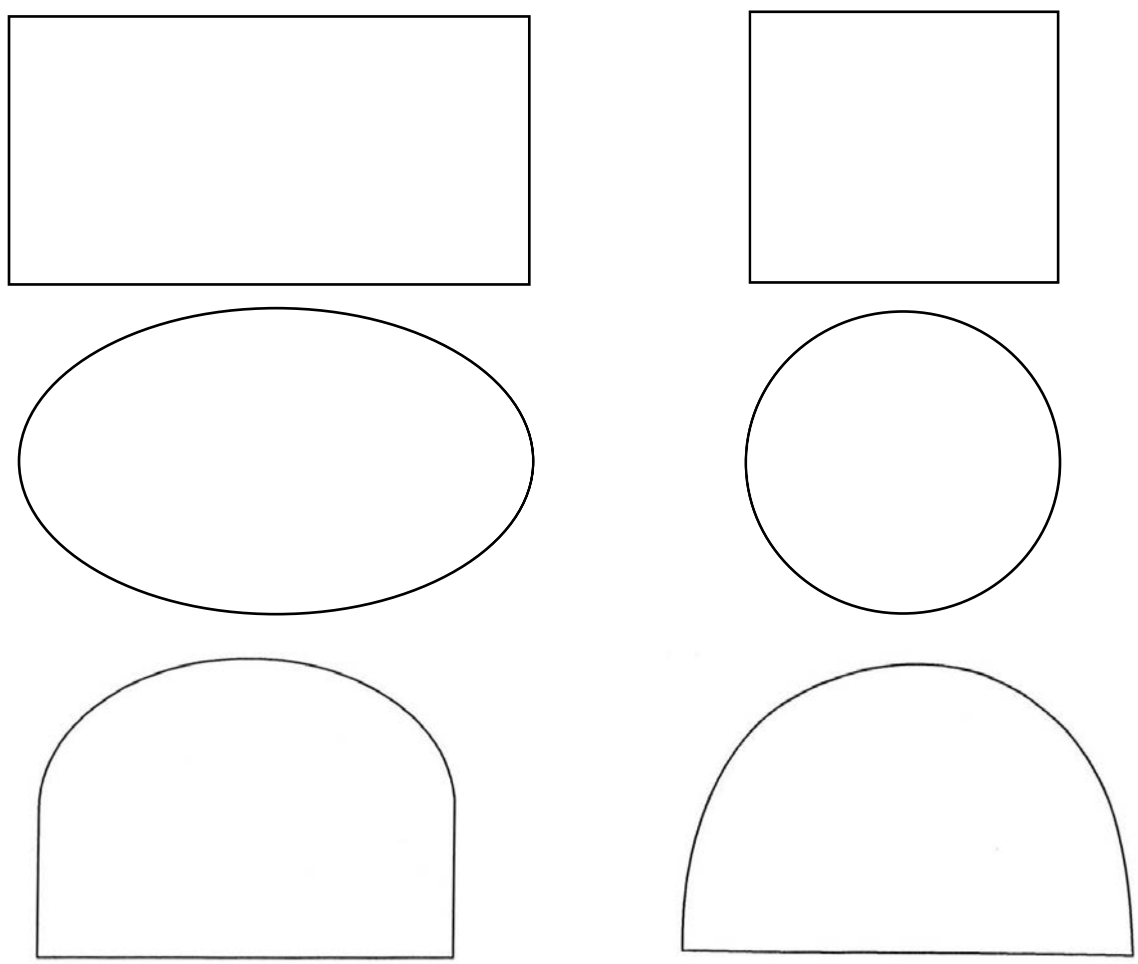
Description:

____

____

____

Typical Culvert Shapes (fill in dimensions)



APPENDIX C
PHOTO LOGS

APPENDIX C. PHOTO LOG

Photo log of select locations within the river corridor.

Photo No. 1 **Description:** Facing upstream at 18 Mile Creek Park, Hamburg, NY	
Photo No. 2 **Description:** Facing upstream at the W Crescent Avenue bridge, Hamburg, NY	

Photo No. 3 **Description:** Facing downstream on Eckhardt Road bridge, Hamburg, NY	
Photo No. 4 **Description:** Facing downstream on Eckhardt Road bridge, Hamburg, NY	

Photo No. 5 **Description:** Upstream face of Zimmerman Road bridge, Hamburg, NY	
Photo No. 6 **Description:** Facing upstream on Zimmerman Road bridge, Hamburg, NY	

Photo No. 7 **Description:** Upstream section of Patchin Road bridge, Boston, NY	
Photo No. 8 **Description:** Facing downstream on Patchin Road bridge, Boston, NY	

Photo No. 9 **Description:** Facing upstream on W Hillcroft Drive bridge, Boston, NY		
Photo No. 10 **Description:** Upstream section of W Hillcroft Drive bridge, Boston, NY		

Photo No. 11 **Description:** Facing downstream on W Hillcroft Drive, Boston, NY	
Photo No. 12 **Description:** Facing downstream on Mill Street bridge, Boston, NY	

Photo No. 13 **Description:** Downstream section of Mill Street bridge, Boston, NY		
Photo No. 14 **Description:** Facing upstream looking at the W Tillen Road bridge, Boston, NY		

Photo No. 15 **Description:** Facing upstream past the W Tillen Road, Boston, NY	
Photo No. 16 **Description:** Facing upstream looking at the Trevett Road bridge during construction of new bridge, Boston, NY (2019)	

Photo No. 17 **Description:** Facing downstream on the (New) Trevett Road bridge during construction, Boston, NY (2020)	
Photo No. 18 **Description:** Facing downstream on the (Old) Trevett Road bridge, Boston, NY	

APPENDIX D

AGENCY AND STAKEHOLDER MEETING SIGN-IN SHEET

MEETING ATTENDEES

SAMUEL BATT, NYSDOT R5

MATT DENO, GOMEZ AND SULLIVAN (PART OF THE CONSULATANT TEAM)

CLYDE DRAKE, SUPERVISOR OF CONCORD

JOE FIEGL, ECDEP-DSM

SHAUN GANNON, OBG (PART OF THE CONSULTANT TEAM)

MARK GASTON, DISTRICT FIELD MANAGER, ERIE COUNTY SWCD

JT GLASS, ERIE CO. DHSES

KADIR GOZ, OBG (PART OF THE CONSULTANT TEAM

DAVID HALL, ERIE COUNTY DEP

GENE HART, TOWN OF WEST SENECA COUNCIL

RYAN HASTINGS, OBG (PART OF THE CONSULTATN TEAM)

SUSAN HOPKINS, HIGHLAND PLANNING (PART OF THE CONSULTANT TEAM)

DAVE JOHNSON, CPL-TOWN OF WEST SENECA

TED MYERS, DEC

KERRIE O'KEEFFE, NYSDEC R9

LAURA ORTIZ, ARMY CORPS

JOANNA PANASIEWICZ, ECDEP/LEWPA

THOMAS R. SNOW, JR., DEC

JEFF SZATKOWSKI, TOWN OF AMHERST

STEVE TANNER, CPL-TOWN OF WEST SENECA

JEN TOPA, HIGHLAND PLANNING (PART OF THE CONSULTANT TEAM)

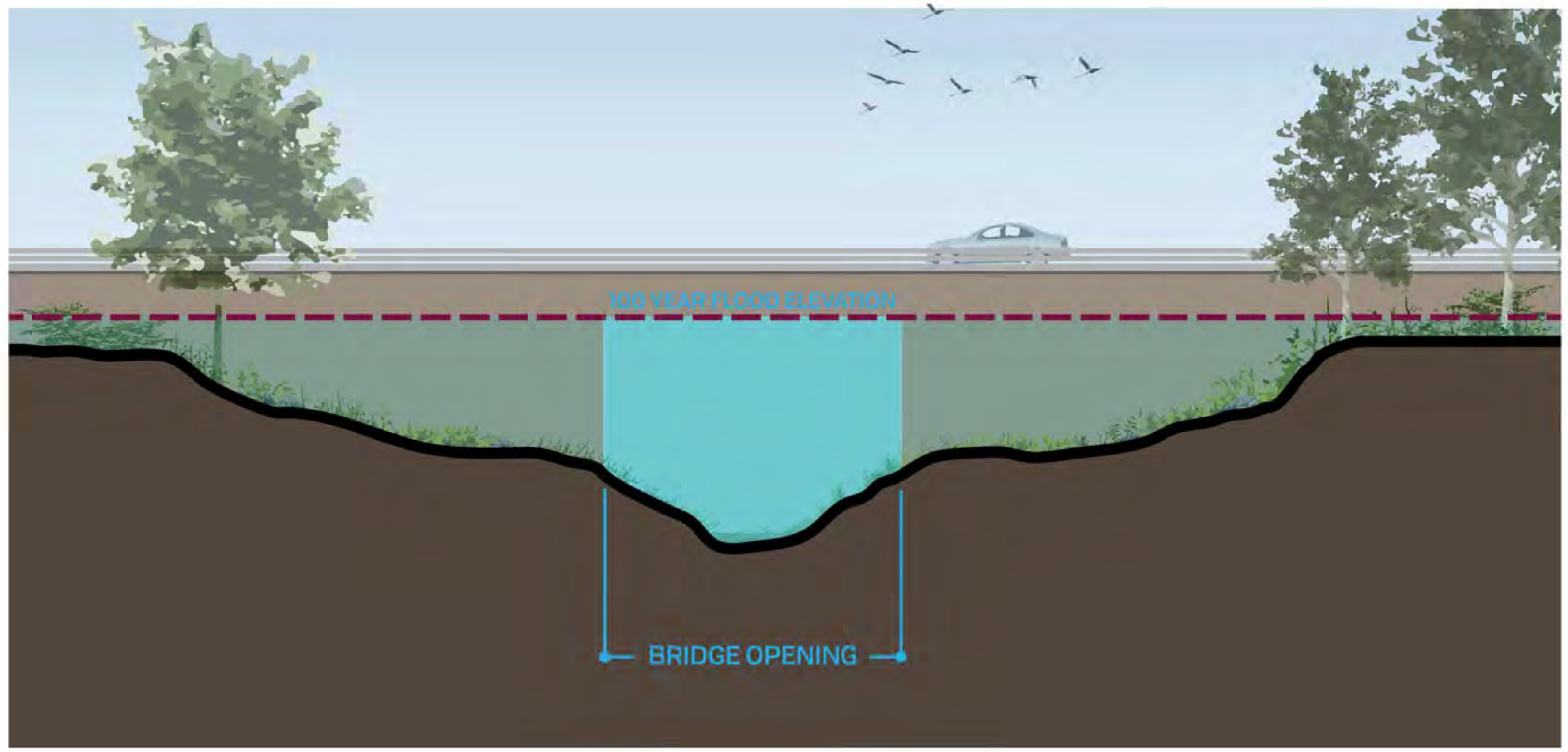
RYAN TOMKO, DEC

GARNELL WHITFIELD, NYS OEM

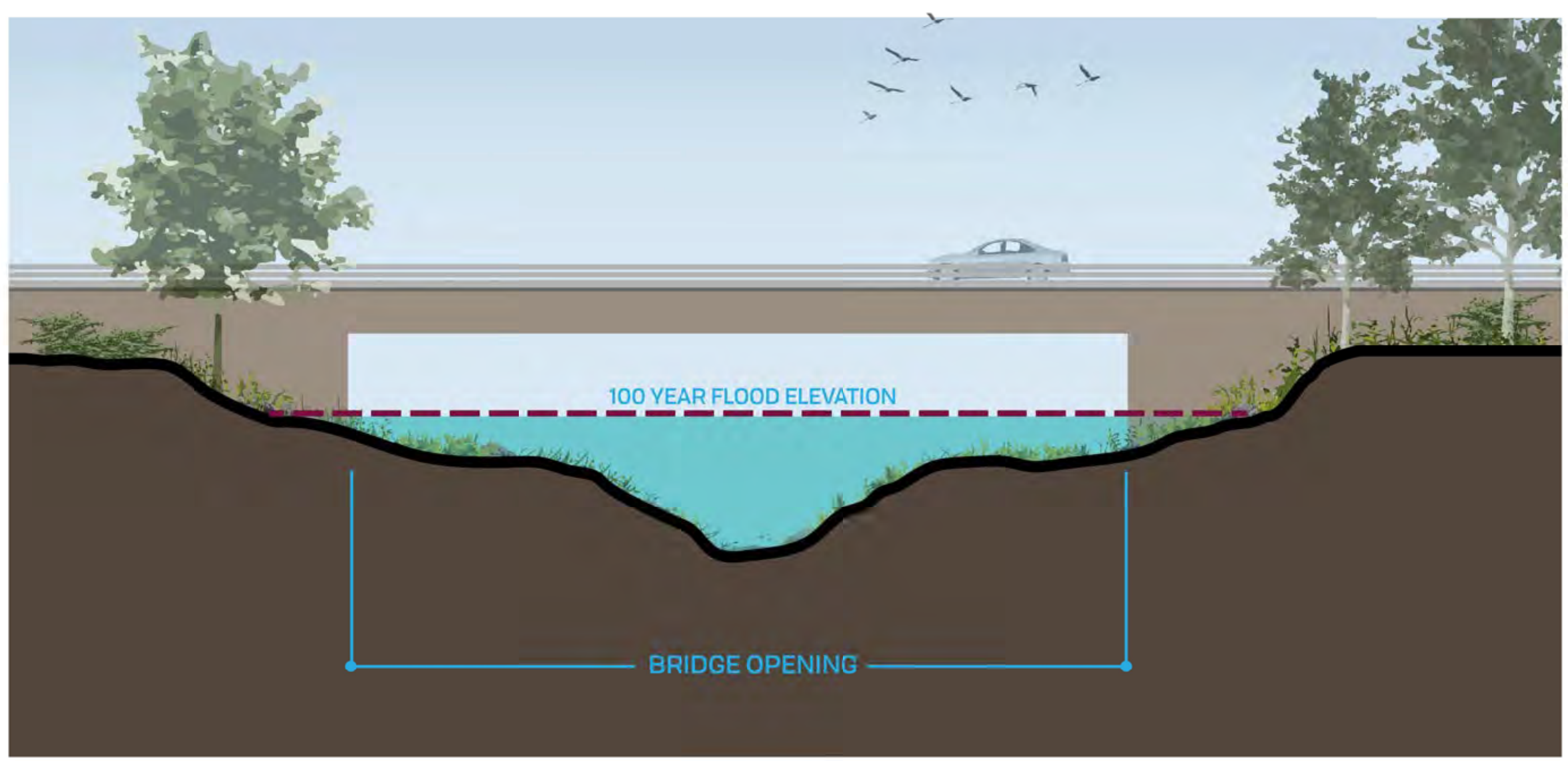
KATHERINE WINKLER, BUFFALO NIAGARA WATERKEEPER

DON ZELAZNY, NYSDEC

APPENDIX E
MITIGATION RENDERINGS

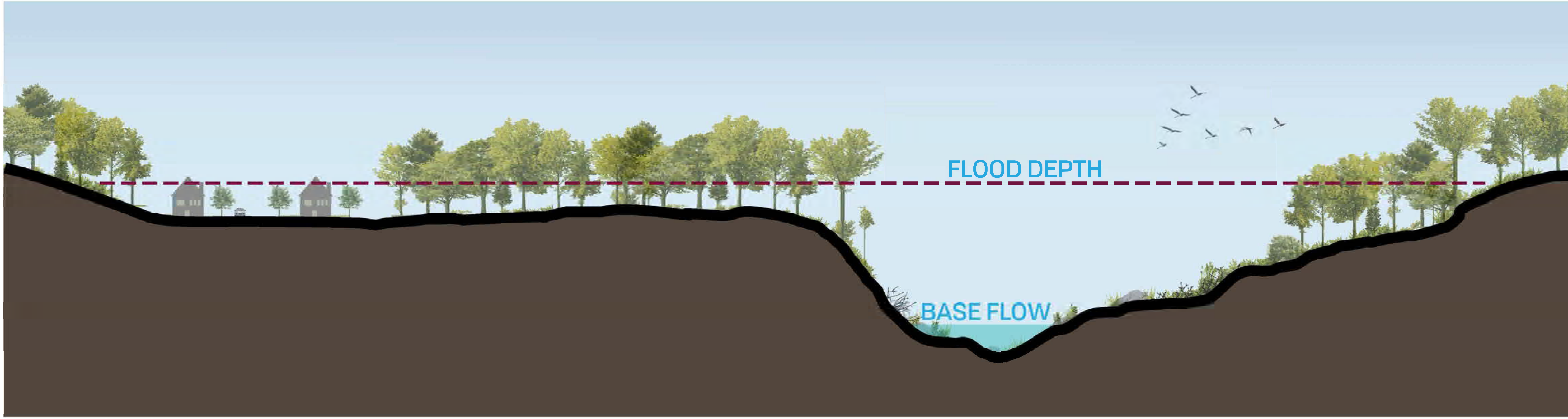


Existing Condition

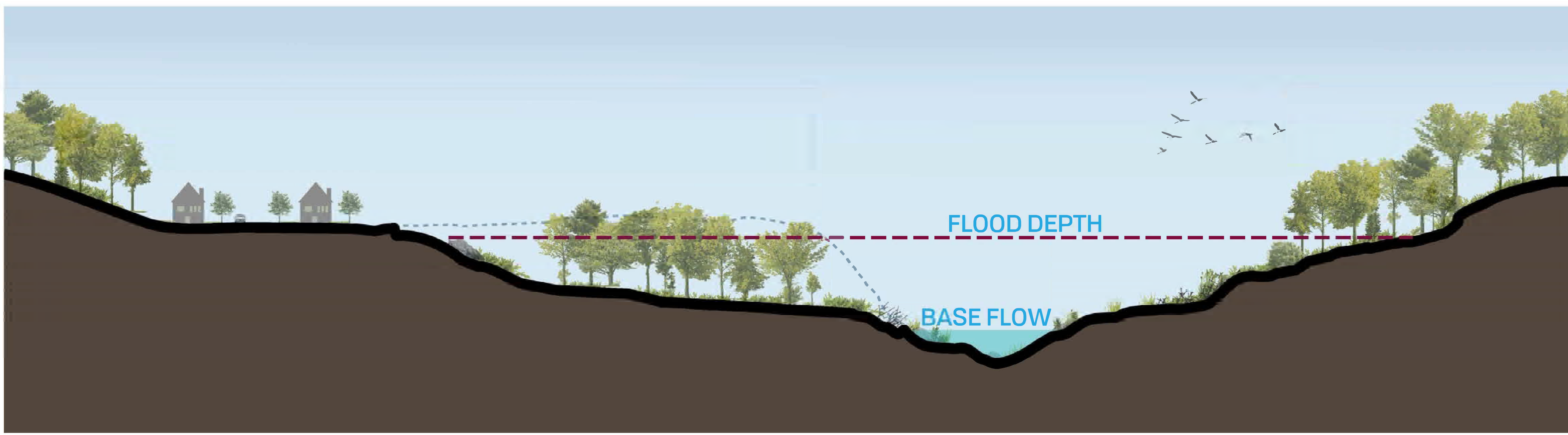


Future Condition

EXPANDED BRIDGE OPENING



Existing Condition



Future Condition

FLOODPLAIN BENCH

APPENDIX F

ICE JAM FLOODING MITIGATION ALTERNATIVES

1. ICE JAM FLOODING MITIGATION ALTERNATIVES

There are several widely accepted and practiced standards for ice jam controls to mitigate the ice jam related flooding. These are referred to as ice jam mitigation strategies and each strategy is very much site dependent. A strategy that works for a certain reach of a river wouldn't work for another reach in the same river due to river morphology and hydrodynamics. Therefore, each of these strategies need to be analyzed with numerical modeling and simulations to check if they work for a considered area/reach of a river before implementing or recommending with the previous observational experience alone. The standard strategies that are widely accepted and practiced in cold region engineering are:

- Ice Booms
- Ice Breaking using Explosives
- Ice breaking using ice-breaker ferries and Cutters
- Installing inflatable dams (Obermeyer Spillways)
- Mixing heated effluent to the cold water
- Removal of Bridge Piers or Heated bridge piers or heated riverbank dikes
- Ice retention Structures
- Ice Forecasting Systems and Ice Management

1.1 Ice booms

Ice booms are the most widely used ice jam control strategy to control ice movement and minimizes surface ice transport. They can be both permanent and temporary structures depending on the emergency measure in high-risk situations. They mainly consist of a series of timber beams or pontoons connected and strung across a river. Once the ice disappears, the booms can be removed if needed and transported elsewhere for storage during the summer months. Ice booms are flexible and can be designed to release ice gradually when overloaded. They can be a relatively cost-effective intervention and can be placed seasonally to reduce potential negative environmental impacts. Ice booms can also be deployed relatively rapidly, rendering them effective as an emergency response measure.

However, the removal of ice booms can be costly since the components of each boom must be disconnected, cleaned, transported and stored until their next deployment. Ice booms can also be ineffective given that ice jams have the potential to circumvent the booms by moving underneath them. Ice booms do not suit all river environments and require low river flow velocity and adequate upstream ice storage capacity.

1.2 Ice breaking using explosives

Thermally grown ice is relatively easy to break up by blasting, while frazil ice is more difficult because it absorbs much of the blast energy. Ice blasting using dynamite is being widely used in rivers where very thick ice jams are formed. It is a very efficient method that can be performed within minutes. It is easily transported to remote locations and does not require any maintenance. Holes are drilled in the ice and dynamite is inserted to blow the ice apart. The most effective results can be achieved by placing the charges underneath the ice surface.

Using dynamite to clear ice can, however, be harmful to the environment. It is also a dangerous method to employ with potentially fatal consequences. Dynamite is not a sustainable solution and can require multiple treatments during extreme cold. It also requires the containment of large areas, which might have to be repeated several times.

1.3 Ice breaking using ice-breaker ferries and Cutters

Ice breakers are specialized vessels designed to break ice jams in wide rivers. They represent a non-structural ice jam mitigation method that is used internationally, in lakes, wide rivers, and oceans. Ice breakers are generally operated when temperatures start to rise, before it reaches the peak cold. They are most suitable for ice sheet breaking (juxtaposed type ice jams), as there are limitations for the ice thickness that they are capable of breaking.

Cutting thick ice covers can also mechanically weaken the ice jams and help relive the internal pressure of an ice-covered channel due to the thick ice cover. A thick ice cover increases the resistance to flow and slowdown the discharge under the ice covers and increase the backwater effects upstream. By cutting the ice cover this pressure can be relieved and the backwater effects can be minimized to reduce upstream flooding potentials. This can also help to control the ice jam breakup and control large ice pieces release from the break-up.

Ice breakers can typically break thick ice covers of up to three to ten feet. Ice breakers have proven to be effective tools for breaking up ice cover on rivers. There are multiple types of ice breakers and, being a mobile solution, they can be flexibly targeted at areas with the most need. Operating ice breakers requires a highly skilled command and crew and are not suitable in all environments. Transporting ice breakers is also relatively difficult, making it a time-consuming and potentially cost-intensive solution.

1.4 Installing inflatable dams (Obermeyer Spillways)

Removing permanent run-of-river low head dams that are prone to ice jams and replacing them with floatable dams can be a good solution for flow control for all seasons. Since the crest elevation can altered, they allow for a control release of incoming ice, allowing it to spillover without jamming. Also, in case of a sudden freeze-up jam that lead to an overnight thick jam can also be broken by frequent or oscillatory movement of lowering and raising the crest to break or weaken the ice jam. Obermeyer Spillway gates are recommended in areas where it is more prone to ice accumulation and flow control is still essential during all seasons.

Obermeyer Spillway Gates consist of a row of steel gate panels installed either at the top of dams or as free-standing structures. The system utilizes a combination of metal flap-gate panels supported by multiple small inflatable “bladders” that adjust the panels' angle and elevation. By controlling the pressure in the bladders, the water flow can be infinitely adjusted within the system control range. Panels can also be designed to include heated abutment plates to prevent ice formation.

1.5 Mixing heated effluent to the cold water

The release of warm water waves into a river from a nearby treatment plants or additions of heated water mixing can help mitigate ice jam formations where the above mentioned alternatives won't work. Provided that the effluent is added to the river prior to ice jam formation, the additional water volume can increase the river flow velocities and prevent ice jam creation in the first place. The wastewater can also be used for the thermal control of ice, as the released warm water can melt or thin ice jams.

1.6 Removal of Bridge Piers or Heated bridge piers or heated riverbank dikes

Bridge piers are a hotspot for capturing surface and suspended frazil ice. When surface ice floes are adhered to the bridge piers and abutments the lateral growth of ice rapidly increase thus snagging more ice on the surface creating an ice bridge across the river. When there are more piers across the river the potential of ice bridging between piers increase due to a series of small ice bridging between two piers can be rapidly form than between longer between the longer pier spans.

Removing bridge piers can lead to high cost construction projects with inconvenience to the daily traffic through the bridge and the structural integrity. Therefore, heated bridge piers can be a good alternative to the existing piers that are prone to more ice cohesion and that can lead to high cost of removing the piers. This will limit the ice adhesion to the bridge and pass through the surface and suspended ice without encouraging snagging, capturing and flocculation of surface ice at bridge piers avoiding the possible ice jams.

Also, the heating of piers can heat the surrounding water and mix with the ambient cold water that will lead to the melt existing surface and suspended ice in the water. This reduces any extra ice generation in the water column.

However, heating bridge piers involves carful installation of the wiring and maintenance of the heating elements and energy costs. More frequent inspections of the bridge piers are also needed since the temperature can affect the concrete composition or special treatment for the concrete is needed.

1.7 Ice retention Structures

Ice retention structures are used to control ice jams by actively initiating jams in more suitable locations where they are less damaging. Ice is captured and retained upstream of residential areas.

Ice retention structures are cost-effective, installation methods are simple, however the design is highly customizable according to the site. A retention structure can be associated with a flood bench so that increased water levels due to ice accumulation can be compromised be allowing more storage in the flood bench. The retention structures don't increase the water level during normal flows.

However, the structures do require ongoing maintenance to remove debris. Channel bed scour is a concern for these structures, therefore, a scour analysis needed to perform in the vicinity of the structure to make sure the ice mitigation strategy will not adversely affect the normal river flow.

1.8 Ice Forecasting Systems and Ice Management

Visual monitoring of the ice formation, and ice cover progressions and water levels are good elements of monitoring the ice conditions of a river during the wintertime, but not sufficient to accurately predict the upstream back water effects or ice jam formations or ice jam break-ups. Ice condition and ice jam monitoring system is a useful tool for emergency ice management but limited in ice forecasting ability.

Ice long-term forecasting and short-term freeze-up and ice jam breakup predictions is a complicated process and challenging due to several reasons. Ice forecasting needs geomorphological, meteorological, coupled thermodynamics and hydrodynamics to identify the factors effecting an ice jam condition.

Therefore, an ice forecasting simulation will not be able to be carried out in a timely manner to help making emergency decisions. Therefore, a good forecasting system that will recommend an ice management plan would and customized ice monitoring strategy would be the most appropriate alternative to follow. An annual ice jam simulation with that accounts for forecasted meteorological and hydrological conditions and simulated ice control strategy that is suitable for the upcoming winter can identify the flood prone areas and enable to calculate the associate risk beforehand. These annual studies can also suggest the type of monitoring that is needed in different reaches or areas. For example, if an area needed to visually monitor the ice formation and ice transport through webcams or need to perform a calculation procedure such as "Freezing-Degree-Day" (FDD) method to predict the thickness of an ice jam to break to make decision when to start breaking. This will help officials to manager the resources and order the equipment and staff available before an emergency occur.

Ramboll suggests that to perform a freeze-up or a break-up ice simulation study before implement or recommend any of the above discussed strategies. The basic data needs and steps involved in an ice simulation analysis is also outlined below.

2. ICE FORECASTING MODEL SIMULATIONS

Freeze-up ice simulation is a complex simulation carried out to predict ice generation, movement and coagulation with the change of air temperature, water temperature and water flow over a period of time. Usually these simulations and carried out for a two to three-month time period. A calibration and validation is also needed to ensure accuracy. A freeze-up or ice jam simulation needs the following input data:

- Accurate river bathymetry created from LiDAR survey or hydro-corrected bathymetric data from the state agencies.
- Weather data such as air temperature, wind condition, cloud cover, snowfall and precipitation data.
- Flow conditions, from gauge data or measured data. (e.g. upstream discharge and downstream water level data).
- Ice conditions data, such as water temperature data, incoming ice concentration, and initial ice cover thickness or initial ice floe concertation's and ice floe thickness.
- Visual observation data that are useful to calibrate the model, such as ice cover leading edge propagation locations, water temperature and ice thickness measurements.

The results of such a simulation, when the results are in agreement with observational data, can lead to a better understanding of ice behavior and associated ice jam flooding in the simulated areas that will aid officials and emergency responders in developing better ice management plans.