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RESILIENT NEW YORK FLOOD MITIGATION INITIATIVE

CAZENOVIA CREEK, ERIE COUNTY, NEW YORK

Prepared for:

Project Team:

RESILIENT NEW YORK FLOOD MITIGATION INITIATIVE
CAZENOVIA 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
ACE	Annual Chance Flood Event
BFE	Base Flood Elevation
BRIC	Building Resilient Infrastructure and Communities
CDBG	Community Development Block Grant
CFA	Consolidated Funding Applications
CFS	Cubic Feet per Second (ft^3/s)
CMIP5	5th Phase of the Coupled Model Intercomparison Project
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	United States Department of Homeland Security
DRRA	Disaster Recovery Reform Act of 2018
EPA	Environmental Protection Agency
EPG	Engineering Planning Grant
ESD	Empire State Development Corporation
ESRI	Environmental Systems Research Institute
EWP	Emergency Watershed Protection
FDD	Freezing Degree-Day
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
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
HMA	Hazard Mitigation Assistance
HSGP	Homeland Security Grant Program
HUD	United States Department of Housing and Urban Development
IPaC	Information for Planning and Consulting
LOMR	Letter of Map Revision
LP3	Log-Pearson Type III
NAVD 88	North American Vertical Datum of 1988
NCEI	National Center for Environmental Information
NFIP	National Flood Insurance Program
NRCS	Natural Resources Conservation Service
NWI	National Wetlands Inventory
NWS	National Weather Service
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation

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
NYSOGS	New York State Office of General Services
NYSOPRHP	New York State Office of Parks, Recreation, and Historic Places
RAMBOLL	OBG, Part of Ramboll
RC	Circularity Ratio
RE	Elongation Ratio
RF	Form Factor
RF	Radio Frequency
RICEN	River Ice Simulation Model
RL	Repetitive Loss
ROM	Rough Order of Magnitude
SHSP	State Homeland Security Program
SIR	Scientific Investigations Report
SQ MI	Square Miles (mi^2)
SRL	Severe Repetitive Loss
USACE	United States Army Corps of Engineers
USFWS	United States Fish & Wildlife Service
USGS	United States Geologic Service
USSCS	United States Soil Conservation Service
WCRP	World Climate Research Programme
WGCM	Working Group Coupled Modelling
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 Cazenovia Creek watershed. The Cazenovia Creek watershed is primarily undeveloped in the upper reaches and becomes more densely developed heading towards the City of Buffalo. Examples of sound floodplain planning include Cazenovia Park and the Cazenovia Park Golf Course. Located within the City of Buffalo, these locations offer flood storage and low-risk floodplain development (USACE 1971).

Reports dating back to the 1970's began exploring ideas to reduce flood damage along Cazenovia Creek, specifically within the City of Buffalo and Town of West Seneca. A 1977 US Army Corps of Engineers (USACE 1977) feasibility study evaluated 14 alternatives, based on a number of factors, such as benefit cost ratio. The only alternative that was economically justified was the construction of an ice retention structure (USACE 1986). In 2000, the USACE performed a detailed study to evaluate possible ice-control structures and their effectiveness. Numerical and physical models were used to evaluate different configurations (Lever et al. 2000). The chosen design consisted of nine 5-ft diameter, 10-ft tall steel-jacketed concrete piers with 12-ft clear spacing, perpendicular to the flow of Cazenovia Creek. Along the right bank, a 300-ft long rip-rap embankment with reinforced concrete curb was constructed, approximately centered on the ice control piers. Construction of the ice control structures began in 2004 and was completed in 2006. Cost of construction was roughly $1.8 million (NYSDEC, n.d.). In 2016, the USACE Buffalo District awarded a $318,000 contract to upgrade the ice control structure; raising the right bank berm, improving the maintenance and access drives, and constructing a pad for debris removal (USACE 2016a).

In addition, there is a Federally constructed Section 208 Clearing & Snagging Project on Cazenovia Creek in the Town of West Seneca between Mill Road (upstream limit) and the New York State Thruway (approximate downstream limit). The NYSDEC and the Town of West Seneca are sponsors of the project with the Town performing routine maintenance. The project is inspected annually by the USACE, NYSDEC and Town of West Seneca.

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 City of Buffalo and Towns of West Seneca and Elma 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 program in response to devastating flooding in communities across the State in the preceding years. A total of 48 high-priority flood prone watersheds across New York State are being addressed through the Resilient NY program. Flood mitigation studies were commissioned using advanced modeling techniques and field assessments to identify priority projects in these 48 flood-prone watersheds, develop state-of-the-art studies to reduce flooding and ice jams, and to improve ecological habitats in the watersheds (NYSGPO 2018). The Cazenovia Creek watershed was chosen as a study site for this initiative.

The New York State Department of Environmental Conservation (NYSDEC) 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 Program 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 Cazenovia Creek began in July of 2019 and a final flood study report was issued in October of 2020.

2. 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 2019 FEMA Flood Insurance Study (FIS) for Erie County, NY. H&H modeling for Cazenovia Creek in the City of Buffalo and Town of West Seneca was completed in 2007 and 1990, 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.

2.1 PUBLIC OUTREACH

An initial project kickoff meeting was held on July 16, 2019, with representatives of the New York State Department of Environmental Conservation (NYSDEC), New York State Department of Transportation (NYSDOT), OBG, Part of Ramboll (Ramboll), Gomez & Sullivan Engineers (GSE), Highland Planning, LLC, Town of West Seneca, Town of Amherst, Erie County Soil and Water Conservation District (ECSWCD), Erie County Department of Environment and Planning and Division of Sewerage Management (ECDEP-DSM), Erie County Department of Homeland Security and Emergency Services (ECDHSES), Lake Erie Watershed Protection Alliance (LEWPA), USACE, Buffalo-Niagara Waterkeepers, and applicable local residents (Appendix D). 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 flood risk assessment tasks.

2.2 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 City of Buffalo and Towns of West Seneca and Aurora as identified in the initial data collection process. Initial field assessments of Cazenovia 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 bank failures, head cuts, bed erosion, aggradation areas, and other unstable 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 Cazenovia Creek watershed lies entirely within Erie County, NY (Figure 1). Cazenovia Creek is the second largest tributary to the Buffalo River with a drainage area of approximately 140 square miles. The creek has a main stem along with an east and west branch generally flowing in a northwest direction. Headwaters of the east and west branches are approximately four miles north of Sardinia, and approximately four miles north of Springville, respectively. The main stream forms just south of the Quaker Road bridge in the Village of East Aurora where the two branches meet. The main stream follows a northwest path to its confluence with the Buffalo River in the City of Buffalo (USACE 1977). Within the Cazenovia Creek watershed, the City of Buffalo and Town of West Seneca were chosen as study areas due to their historical flood records and hydrologic conditions of the creek in these areas. Figures 3-1, 3-2 and 3-3 depict the stream stationing along Cazenovia Creek, and the study area in the City of Buffalo and Town of West Seneca, respectively.

3.2 ENVIRONMENTAL CONDITIONS

An overview of the environmental and cultural resources within the Cazenovia 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 New York State Department of Environmental Conservation (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).

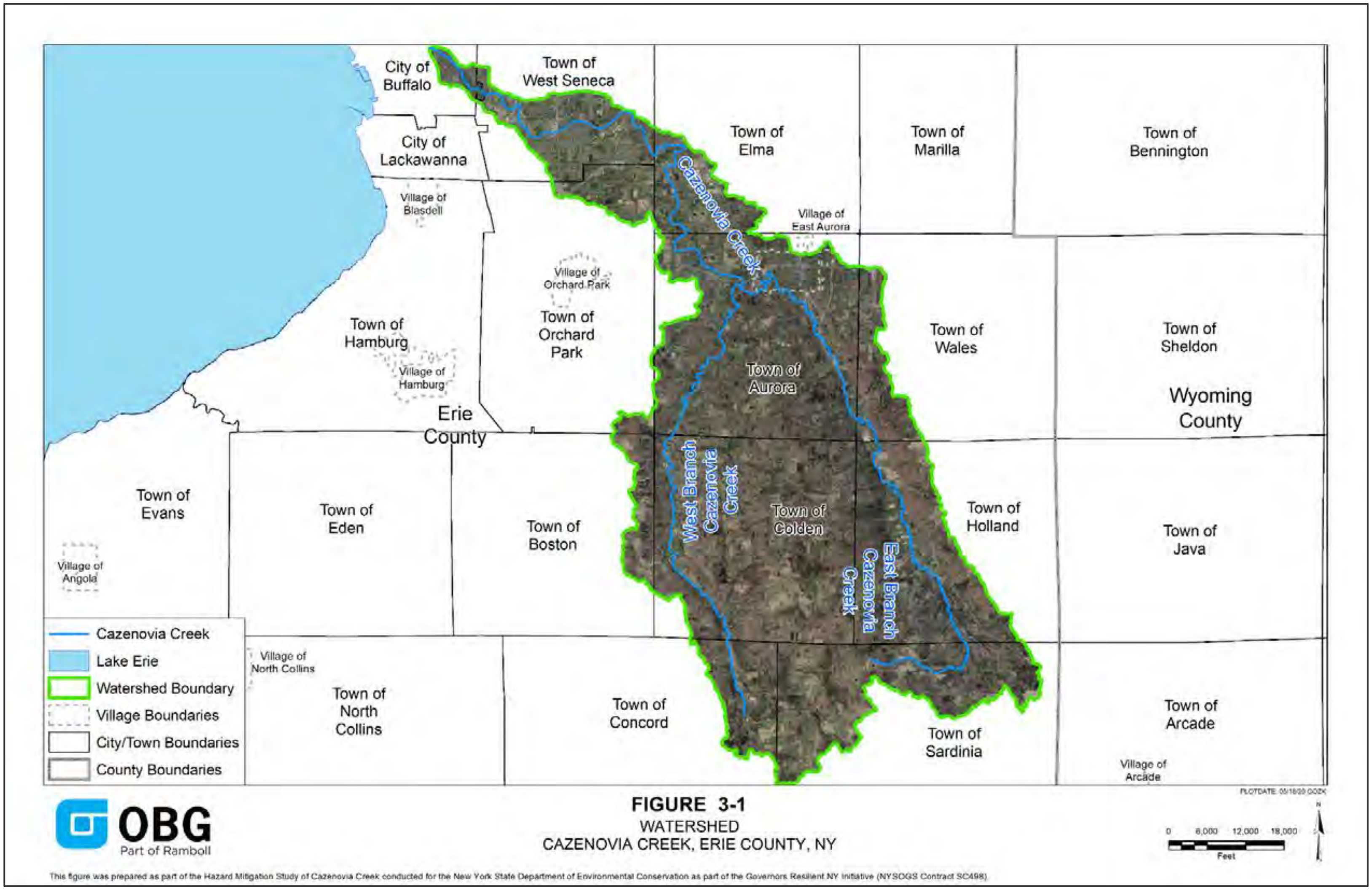

Figure 3-1. Cazenovia Creek Watershed, Erie County, NY.

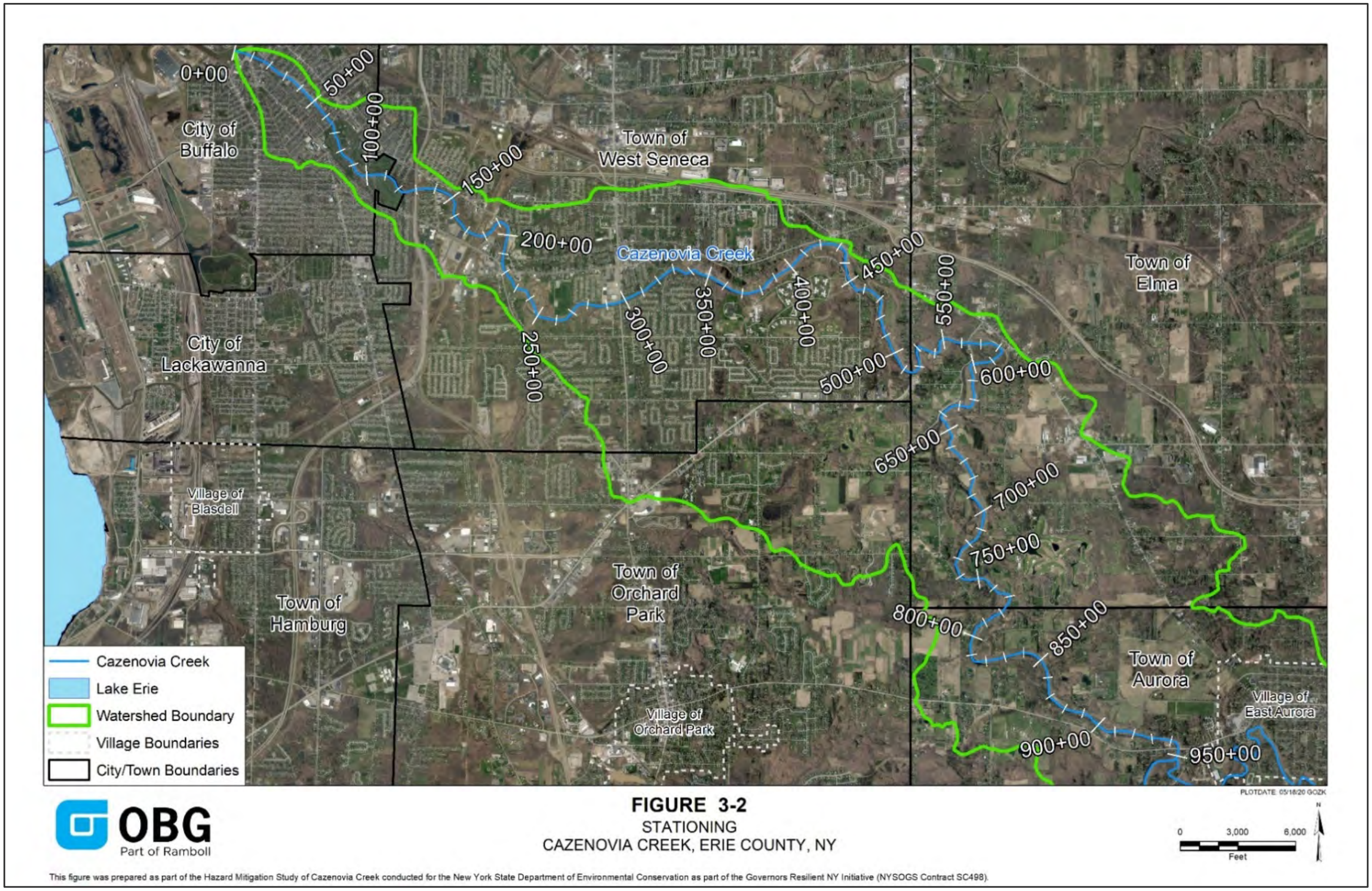

Figure 3-2. Cazenovia Creek Watershed, Erie County, NY.

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

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-ft buffer zone around the wetland in which the actual wetland may occur. Several state-regulated freshwater wetlands are located within the Cazenovia Creek watershed. The National Wetlands Inventory (NWI) was reviewed to identify national wetlands and surface waters (Figure 3-4). The Cazenovia Creek watershed includes a riverine habitat, freshwater emergent wetlands, and freshwater forested / shrub wetlands (NYSDEC 2020).

3.2.2 Sensitive Natural Resources

No areas designated as significant natural communities by the NYSDEC were mapped in the Cazenovia Creek watershed (NYSDEC 2020).

3.2.3 Endangered or Threatened Species

The Environmental Resource Mapper shows that the project area 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 Information for Planning and Consultation (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.

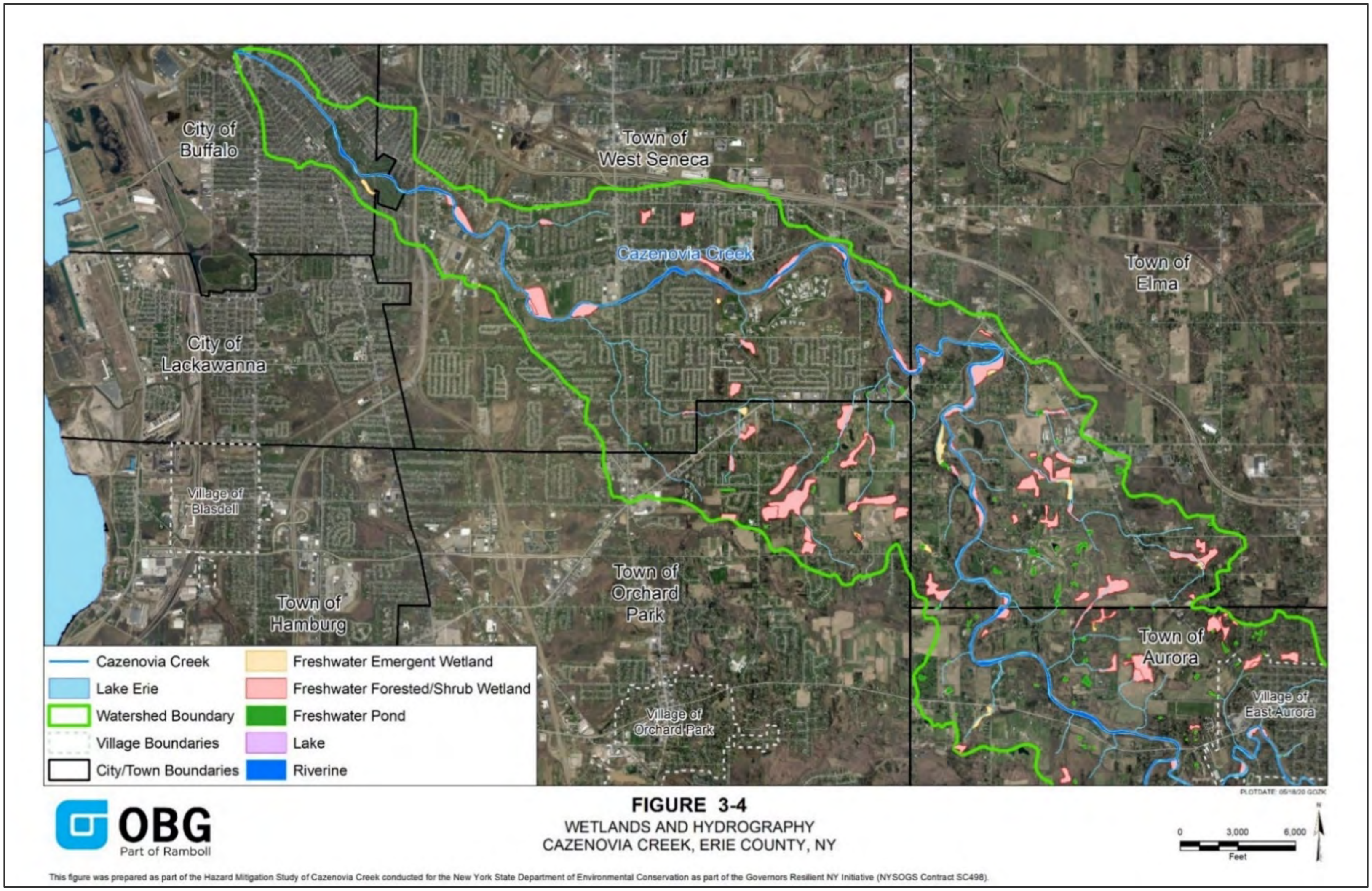

Figure 3-4. State Regulated Freshwater Wetlands, Cazenovia Creek Watershed, Erie County, NY.

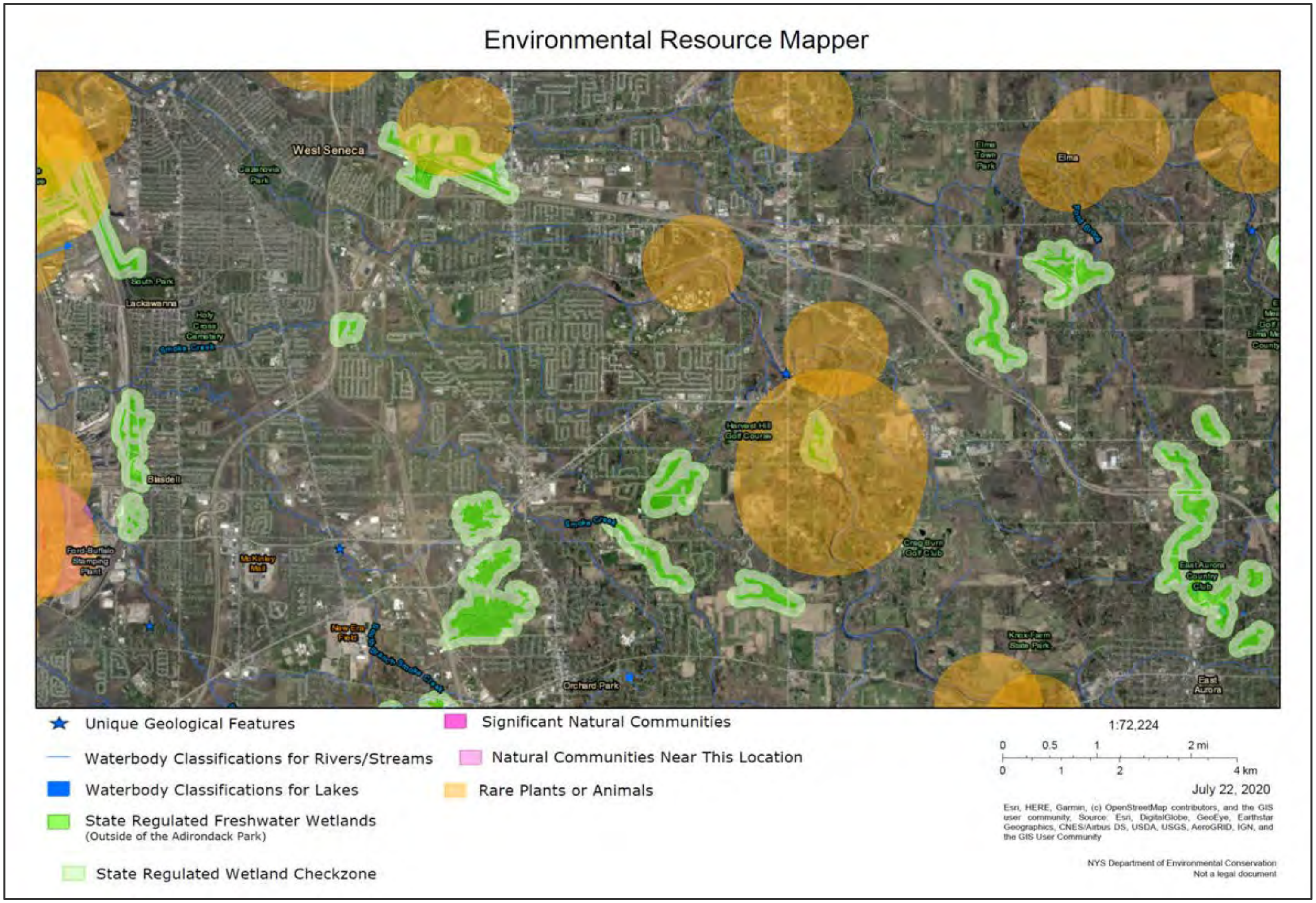

Figure 3-5. Significant Natural Communities and Rare Plants or Animals, Cazenovia Creek Watershed, Erie County, NY.

Table 1. USFWS IPaC Listed Migratory Bird Species

Common Name	Scientific Name	Level of Concern	Breeding Season
Bald Eagle	*Haliaeetus leucocephalus*	Non-BCC Vulnerable[1]	Breeds Sep 1 to Aug 31
Black-billed Cuckoo	*Coccyzus erythropthalmus*	BCC Rangewide (CON)[2]	Breeds May 15 to Oct 10
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
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
Snowy Owl	*Bubo scandiacus*	BCC Rangewide (CON)[2]	Breeds elsewhere
Wood Thrush	*Hylocichla mustelina*	BCC Rangewide (CON)[2]	Breeds May 10 to Aug 31

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).

3.2.4 Cultural Resources

The National Register of Historic Places lists historic places worthy of preservation, as authorized by the National Historic Preservation Act of 1966 (National Park Service 2014) (https://www.nps.gov/maps/full.html?mapId=7ad17cc9-b808-4ff8-a2f9-a99909164466). Cazenovia Creek runs through the Cazenovia Park – South Park System. 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.

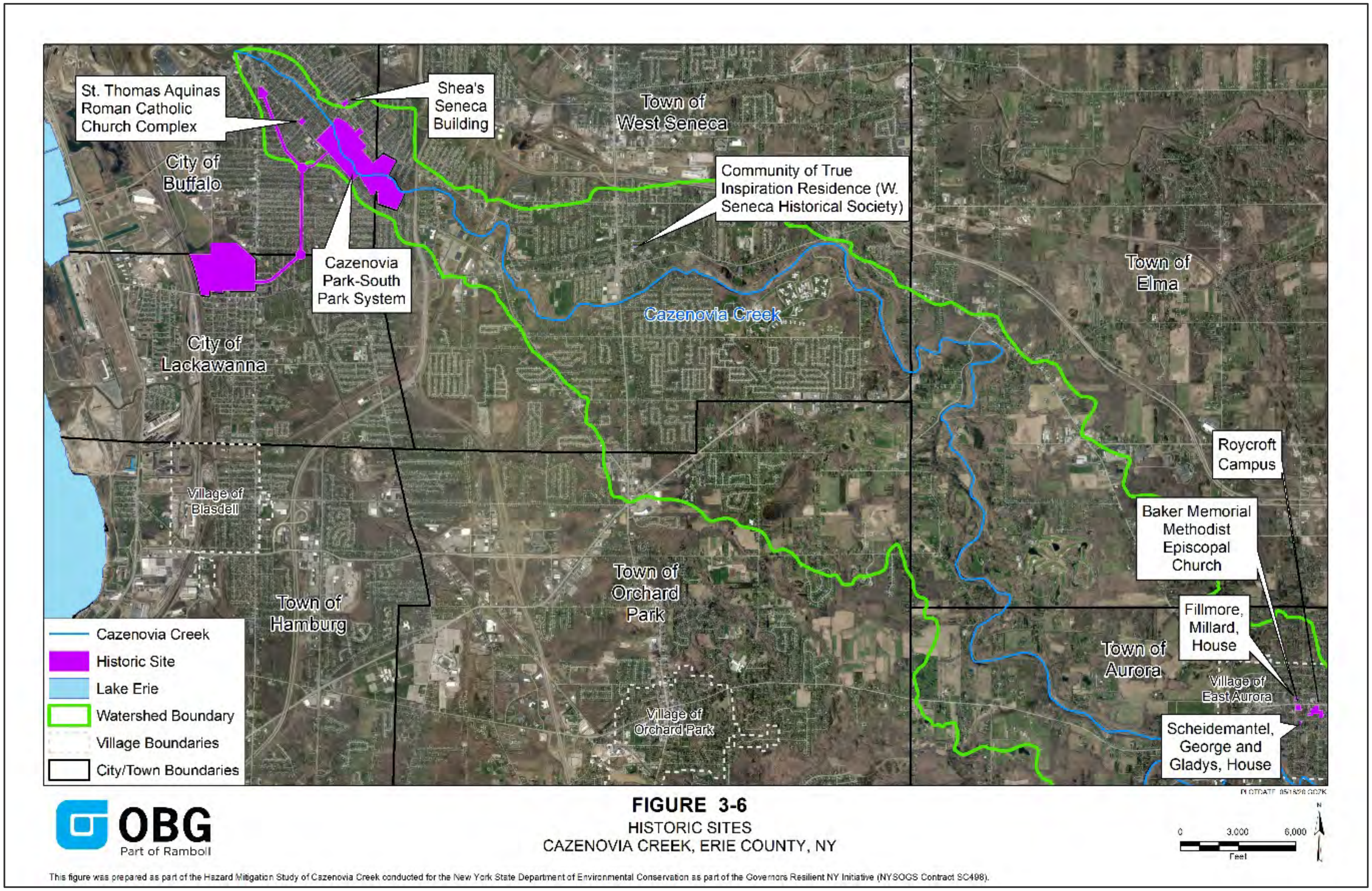

Figure 3-6. National Register of Historic Places Map, Cazenovia Creek Watershed, Erie County, NY.

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 City of Buffalo and Town of West Seneca, the current effective FEMA FIS was completed on June 7, 2019. According to the FIS, the hydrologic and hydraulic analyses completed were a re-delineation of the original FEMA H&H study for both municipalities. The FEMA FIS did include Cazenovia Creek in the re-delineation study (FEMA 2019a; FEMA 2019b; FEMA 2020).

Re-delineation 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 re-delineation update are more accurate floodplain boundaries when compared to current ground conditions. Re-delineation of floodplain boundaries can be applied to both riverine and coastal studies. No new engineering analyses are performed as part of the re-delineation methodology; however, re-delineation 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 re-delineation 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 re-delineate coastal high hazard areas (FEMA 2015a).

The FIRM for the Cazenovia 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). Cazenovia Creek is a Regulatory Floodway, which is defined as the watercourse channel 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. 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 foot (FEMA 2000).

Figure 3-7 is an example FIRM that includes a portion of Cazenovia Creek in the Town of West Seneca, NY. The flood zones indicated in the Cazenovia Creek study area where mandatory flood insurance purchase requirements apply are Zones A and AE. 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. Zone AE is the flood insurance rate zone that corresponds to the 100-year floodplains, determined in the FIS by detailed methods. The BFEs shown were derived from hydraulic analyses (FEMA 2019c).

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 (FEMA 2000).

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, Cazenovia Creek, Town of West Seneca, Erie County, NY.

3.3 WATERSHED LAND USE

The Cazenovia Creek stream corridor is largely comprised of forested lands (56%) in the upper and middle reaches, with an increase in developed lands as the stream approaches the confluence with the Buffalo River in the City of Buffalo (Yang et al. 2018). Within the City of Buffalo, the floodplain is completely utilized by a combination of residential areas, a park and a golf course. The park and golf course are excellent examples of intentional floodplain planning and utilization (USACE 1971). The park often becomes inundated during ice-jam events, much more frequently than residential areas are affected (URS 2015).

3.4 GEOMORPHOLOGY

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).

The bedrock geology of the Cazenovia Creek basin consists of the Hamilton Group (Marcellus and Moscow Formations) at the confluence with the Buffalo River then transitions to the Sonyea and Genesee, Java and West Falls, and Canadaway Groups traveling upstream towards the headwaters. The City of Buffalo and Town of West Seneca are underlain with bedrock predominately from the Hamilton Group consisting of Skaneateles, Marcellus, and Ludlowville Formations. The Hamilton Groups consists primarily of hales and limestones and has formed a band approximately 4 miles wide in Erie County, NY (USSCS 1986).

The Cazenovia Creek basin is characterized by mostly level floodplain to the south, with steep escarpments and shale cliffs on the north. Both the east and west branches of the creek have become deeply entrenched in the Allegheny Plateau, with eroded materials depositing on the Erie Plain, and the channel often becoming partially obstructed by extensive shoals (USACE 1979). Rock is often exposed in portions of the channel bottom and at several of the bridges within the reach (USACE 1971).

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 Cazenovia Creek. Cazenovia Creek has an average slope of 0.24% over the profile stream length. The creek’s streambed lowers approximately 200 vertical feet over this reach from an elevation of roughly 760-ft above sea level (NAVD 88) at in the Town of Aurora, to 560-ft above sea level at the confluence of Buffalo River in the City of Buffalo (FEMA, 2019b).

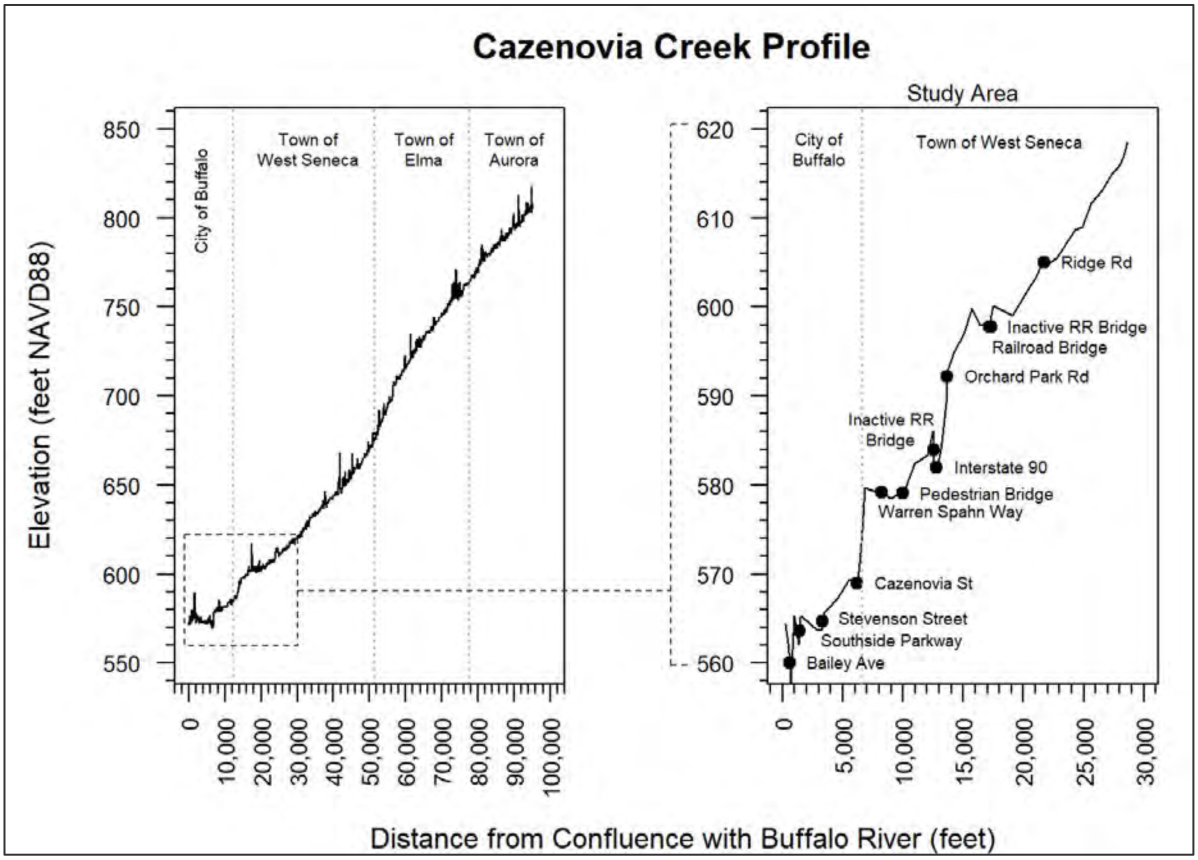

Figure 3-8. Cazenovia Creek profile of stream bed elevation and channel distance from the confluence with the Buffalo River.

In addition, there are numerous locations where sediment depositional aggradation is occurring within the channel of Cazenovia Creek, such as the Gossel's Island shoal formation. Aggradation is a natural 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 may restrict flow by reducing the in-channel flow area and may act as catchpoints for ice pieces during ice breakup events, potentially increasing open water flood risks and ice jam formations (Mugade and Sapkale 2015).

3.5 HYDROLOGY

Cazenovia Creek drains an area of approximately 137 square miles, is approximately 38 miles in length from its source to the confluence with Buffalo Creek, in the southwestern portion of New York State in Erie County. The basin takes the shape of a triangle with the apex at its mouth, and a base with a width of approximately three miles at the confluence of the east and west branches. From the confluence of the branches to the source, the basin is roughly rectangular in shape with a width of eight miles and length of 12 miles. The floodplain is narrow and well defined. Within the study area, Cazenovia Creek has a slope of approximately 12 feet per mile. After the confluence with the Buffalo River, the flow continues an additional six miles to Lake Erie (USACE 1966).

Table 2 is a summary of the basin characteristic formulas and calculated values for the Cazenovia 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 parameter in miles (USGS 1978).

Table 2. Cazenovia Creek Basin Characteristics Factors

Factor	Formula	Value
Form Factor (R_F)	A / B_L^2	0.24
Circularity Ratio (R_C)	$4*\pi*A / B_P^2$	0.23
Elongation Ratio (R_E)	$2 * (A/\pi)^{0.5} / B_L$	0.55

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 Buffalo 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 is a USGS stream gaging station on Cazenovia Creek, USGS 04215500 at Ebenezer, NY. This has been used as the representative hydraulic dataset due to the robustness of the data collected, and the extended 87-year time period over which it was collected. An effective FEMA Flood Insurance Study (FIS) for Erie County was issued on June 7, 2019, which included a redelineation study for Cazenovia Creek. Drainage area, in square miles, and peak discharge, in cubic feet per second, information for Cazenovia Creek at select locations is summarized in Table 3 from the effective FEMA FIS (FEMA 2019b).

Table 3. Cazenovia 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 Buffalo River	137.2	0+00	11,700	14,800	16,400	20,200
At abandoned railroad bridge	136.1	12+588	*	*	15,760	*
Upstream of confluence with Ebenezer Brook	134.2	19+314	*	*	15,610	*

*Data not available

According to the effective FEMA FIS, for Cazenovia Creek in the Town of Aurora, discharge-frequency relationships were established using five USGS gaging stations, including Cayuga Creek near Lancaster, Cazenovia Creek at Ebenezer and Buffalo Creek at Gardenville. Flood flow frequencies were determined by the USACE, Buffalo District using USGS Water Resources Bulletin 17. In the City of Buffalo, a similar analysis was done; however, this one included nine USGS gaging stations and performed a log-Pearson Type III analysis. The regional equations determined in that study were also extended to cover watersheds with drainage areas of less than 15 square miles. In the Town of West Seneca, Cazenovia Creek was studied using USGS Water Resources Investigations (WRI) 79-83. For Cazenovia Creek East Branch in the Towns of Aurora and Holland and Cazenovia Creek West Branch in the Towns of Aurora and Colden, discharge-frequency relationships were established using five USGS gaging stations, including Cayuga Creek near Lancaster, Cazenovia Creek at Ebenezer and Buffalo Creek at Gardenville. Flood flow frequencies were determined by the USACE, Buffalo District using USGS Water Resources Bulletin 17 (FEMA 2019b).

General limitations of the FEMA FIS methodology include: the limited regional flood frequency curves used to calculate discharge-frequency relationships, the age of the methodologies used in light of recent advances in H&H computations and modeling, and the lack of updated peak discharge data in the LP3 analysis when performing a FEMA redelineation study. These limitations represent outdated methodologies for determining discharge-frequency relationships and introduce error at multiple stages in the calculations, which can lead to over or under estimations of peak discharges.

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 Cazenovia Creek in hydrologic region 5, 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 (A, measured in square miles), main channel slope (SL, measured in feet/mile), and mean annual precipitation (P, measured in inches), typical of Region 5. By using these characteristics in the calculation, the peak discharge values have increased accuracy and decreased standard errors by approximately 10% for a 1% 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 Cazenovia 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 Cazenovia Creek at the same locations as the FEMA FIS peak discharges.

Table 4. USGS *StreamStats* Peak Discharge for Cazenovia 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 Buffalo River	137.2	0+00	11,400	16,300	18,500	24,040
At abandoned railroad bridge	136.1	12+588	11,500	16,600	18,900	24,580
Upstream of confluence with Ebenezer Brook	134.2	19+314	11,760	16,900	19,200	25,080
Approximately 1,325 ft downstream of Big Tree Road (at Route 20A bridge)	116.0	932+75	9,900	12,800	14,800	16,800
Approximately 800 ft upstream of confluence with Cazenovia Creek West Branch	60.0	958+00	5,100	6,700	7,300	8,700
Approximately 800 ft upstream of confluence with Cazenovia Creek East Branch	56.0	966+00	4,800	6,100	6,700	8,100

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% 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%) of the calculated peak discharges would be within one standard error of the actual peak discharge, 95.4% would be within two standard errors, and almost all (99.7%) 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

Based on the *StreamStats* standard error calculations, the majority of FEMA FIS peak discharges were determined to be outside of the acceptable range (95% confidence interval). 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 throughout the Cazenovia Creek watershed, and is not affected by the general limitations of the FEMA FIS methodology (e.g. limited regional analysis, outdated computational and modeling methodologies, extrapolation of regional analysis results).

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 Cazenovia 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 within the study area along Cazenovia Creek as derived from the USGS *StreamStats* program (Ries et al. 2017).

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

(Source: Ries et al. 2017)					
Flooding Source and Location	**Drainage Area (Sq. Miles)**	**River Station (ft)**	**Bankfull Discharge (cfs)**	**Bankfull Width (ft)**	**Bankfull Depth (ft)**
At confluence with Buffalo River	139	0+00	3060	134	3.47
Cazenovia St. Bridge	139	61+84	3060	134	3.47
USGS Gage 04215500	136	218+09	3000	132	3.45
Mill Rd. Bridge	130	325+70	2890	130	3.41
US Route 20 Bridge	126	513+57	2820	128	3.38

3.6 INFRASTURCTURE

According to the FEMA FIS, there exists a portion of Cazenovia Creek between the confluence with the Buffalo River and Cazenovia Park in the City of Buffalo, with concrete lined sidewalls and a manmade channel. These portions of the creek were designed to be able to convey the 1 percent annual chance flood discharge (FEMA 2019b).

According to the NYSDEC Inventory of Dams dataset (2019), there are three dams within the Cazenovia Creek watershed as identified by the NYSDEC. All three of the dams are purposed as Recreational, while two out of the three dams are hazard class D with the other dam hazard class A. 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 A are also referred to as “low hazard” dams, which are defined as a dams where a failure is unlikely to result in damage to anything more than isolated or unoccupied buildings, undeveloped lands, minor roads such as town or county roads; is unlikely to result in the interruption of important utilities, including water supply, sewage treatment, fuel, power, cable or telephone infrastructure; and/or is otherwise unlikely to pose the threat of personal injury, substantial economic loss or substantial environmental damage. Table 7 lists the dams that are along Cazenovia Creek, including hazard codes and purpose for the dam (NYSDEC 2019).

Table 7. Inventory of Dams along Cazenovia Creek

(Source: NYSDEC 2019)						
Dam Name	**Municipality**	**Owner**	**State ID**	**River Structure**	**Hazard Code**	**Purpose**
Cazenovia Creek Dam	City of Buffalo	City of Buffalo	011-0310	Cazenovia Creek	D	Recreation
Crag Burn Golf Course Pond Dam	Town of Elma	Private	017-3850	Tributary	A	Recreation
Peter Flickinger Dam	Town of Aurora	Private	017-3513	Tributary	D	Recreation

Major bridge crossings over Cazenovia Creek include US Route 62, Southside Parkway, Stevenson Street, Cazenovia Street, Warren Spahn Way, I-90, NY-240, Ridge Road, NY-277, Mill Road, Leydecker Road, and US-20. Additionally, there is a pedestrian bridge across the creek at Cazenovia Park Golf Course, and a Norfolk Southern Railroad bridge upstream of NY-240. Bridge lengths and surface widths for NYSDOT bridges were revised as of February 2019. Table 8 summarizes the infrastructure data for bridges that cross Cazenovia Creek with (NYSDOT 2016; FEMA 2019b). No existing data could be found for any of the abandoned railroad bridges and due to safety concerns, field staff were unable to perform measurements on these structures. Figure 3-9 displays the locations of the high and low-risk constriction point bridges that cross Buffalo Creek in Erie County.

Table 8. Infrastructure Crossing Cazenovia Creek in Study Area

(Source: NYSDOT 2016)

Roadway Carried	River Station (ft)	NYSDOT BIN	Primary Owner	Bridge Length (ft)	Deck Width[1] (ft)	Hydraulic Capacity (% Annual Chance)
US Route 62	4+68	2028320	City of Buffalo	178	56	1
Southside Parkway	14+00	2260720	City of Buffalo	132	33.5	2
Stevenson Street	33+35	2260740	City of Buffalo	134	33.5	10
Cazenovia Street	61+84	2260690	City of Buffalo	117	42	0.2
Warren Spahn Way	82+53	2260710	City of Buffalo	122	35	1
Golf Course Suspension Bridge	99+91	2260320	City of Buffalo	164	6.5	0.2
Abandoned Railroad Bridge	125+62	N/A	N/A	N/A	N/A	1*
I-90	127+33	5512119	NYS Thruway Authority	361	110.3	1*
NY-240	136+80	1042600	NYSDOT	166	40	1*
Railroad bridge	171+72	N/A	Norfolk Southern Railway Co.	N/A	N/A	1*
Abandoned Railroad	172+79	N/A	N/A	N/A	N/A	1*

Ridge Road	216+92	3326930	Erie County	169	52	n/a*
NY-277	296+55	1044220	NYSDOT	241	52	1*
Mill Road	325+70	2260400	Erie County	120	24.3	1*
Leydecker Road	413+05	3328840	Erie County	202	25	1*
US Route 20	513+57	1015520	NYSDOT	831	56	0.2

[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).
* only 1% annual WSEL profile shown on profile plot

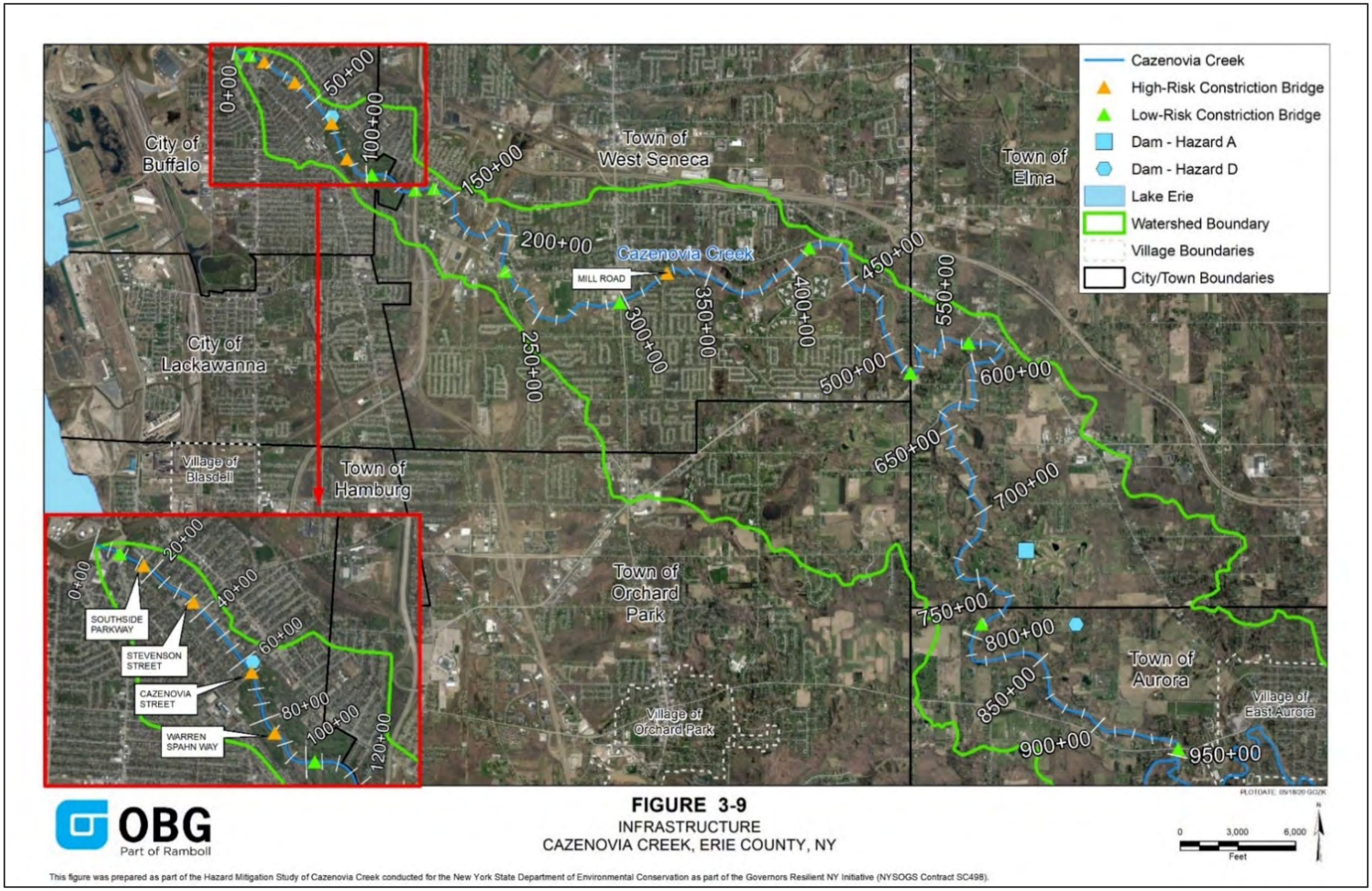

Figure 3-9. Infrastructure, Cazenovia Creek Watershed, Erie County, NY.

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 bridges along Cazenovia Creek, the FEMA FIS profile of Cazenovia Creek was used to determine the lowest annual chance flood elevation to flow under the low chord of a bridge without causing an appreciable backwater condition upstream (Table 8) (FEMA 2019b).

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 Cazenovia Creek within the study area.

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

Source: (FEMA 2019b)				
Bridge Crossing	**River Station (ft)**	**2-Percent Water Surface Elevation (ft NAVD88)**	**1-Percent Water Surface Elevation (ft NAVD88)**	**Difference in Water Surface Elevations (ft NAVD88)**
US Route 62	5+80	582.5[1]	584.0[1]	1.5
Southside Parkway	14+00	582.5[1]	585.0[1]	2.5
Stevenson Street	33+20	585.0	587.0	2.0
Cazenovia Street	62+10	588.0	590.0	2.0
Warren Spahn Way	82+50	592.5	593.0	0.5
Golf Course Suspension Bridge	99+90	596.0	597.0	1.0
Abandoned Railroad Bridge	125+62	*	601.0	N/A
I-90	127+33	*	601.0	N/A
NY-240	136+80	*	601.0	N/A
Railroad Bridge	171+72	*	613.0	N/A
Abandoned Railroad Bridge	172+79	*	613.0	N/A
Ridge Road	216+92	*	621.0	N/A
NY-277	296+55	*	632.0	N/A
Mill Road	325+70	*	640.0	N/A
Leydecker Road	413+05	*	658.0	N/A
US Route 20	513+57	684.0	686.0	2.0

* Data not available for the 0.2, 2, and 10% annual chance flood hazard

[1] Water surface elevations affected by backwater from Buffalo River

In assessing hydraulic capacity of the bridges located in the identified high-risk areas along Cazenovia Creek, the FEMA FIS profiles for were 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, the Stevenson Street bridge does not meet the NYSDOT guidelines for 2-feet of freeboard over the 2% annual chance flood for bridges. Since the FEMA FIS profiles only provided the 1% annual chance flood hazard plot for a number of structures within the study area, the hydraulic capacity of the remaining structures was unable to be determined. US Route 62 and the Southside Parkway also do not meet the freeboard guidelines; however, these structures are influenced by backwater from the Buffalo River according to the FEMA FIS with no data available for non-backwater conditions at these structures.

In addition, the Stevenson Street, Abandoned Railroad (river station 172+79), and Ridge Road bridges do not meet the new draft CRRA climate change infrastructure guidelines as described above based on the FEMA FIS profiles. The low chord elevations do not provide the recommended hydraulic capacity of 2-feet of freeboard over the elevation of a flood with a 1% annual chance. US Route 62 and the Southside Parkway also do not meet the new draft CRRA freeboard guidelines when taking into account the influence of backwater from the Buffalo River according to the FEMA FIS (NYSDEC 2018; FEMA 2019b).

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 width and discharge for each structure along Cazenovia Creek. Table 10 indicates that in the study area, there are 4 bridges that have bridge openings that are smaller than the bankfull widths: Southside Parkway, Cazenovia Street, Warren Spahn Way, and Mill Road. In addition, there is one bridge with an opening that is equal to the bankfull width: Stevenson Street.

The structures that do not span the bankfull width of stream or that are smaller than the bankfull width cause water velocities to slow and contract in order to pass through the structures, which can cause sediment depositional aggradation and the accumulation of sediment and debris. Aggradation can lead to the development of sediment and sand bars, 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.

Table 10. Hydraulic Capacity of Bridges Crossing Cazenovia Creek

Source: (NYSDOT 2016; Ramboll 2019; USGS 2017)						
Roadway Carried	**River Station (ft)**	**Primary Owner**	**Bridge Length (ft)**	**Bankfull Width (ft)**	**Bankfull Discharge (cfs)**	**Annual Chance Flood Event Equivalent[1] (%)**
US Route 62	4+68	City of Buffalo	178	134	3,060	> 80%
Southside Parkway	14+00	City of Buffalo	132	134	3,060	> 80%
Stevenson Street	33+35	City of Buffalo	134	134	3,060	> 80%
Cazenovia Street	61+84	City of Buffalo	117	134	3,060	> 80%
Warren Spahn Way	82+53	City of Buffalo	122	133	3,040	> 80%
Golf Course Suspension Bridge	99+91	City of Buffalo	164	133	3,040	> 80%
Abandoned Railroad Bridge	125+62	N/A	N/A	133	3,040	> 80%
I-90	127+33	NYS Thruway Authority	361	133	3,040	> 80%
NY-240	136+80	NYSDOT	166	133	3,040	> 80%
Railroad bridge	171+72	Norfolk Southern Railway Co.	N/A	133	3,020	> 80%
Abandoned Railroad	172+79	N/A	N/A	133	3,020	> 80%
Ridge Road	216+92	Erie County	169	132	3,000	> 80%
NY-277	296+55	NYSDOT	241	130	2,910	> 80%
Mill Road	325+70	Erie County	120	130	2,890	> 80%

Source: (NYSDOT 2016; Ramboll 2019; USGS 2017)						
Roadway Carried	**River Station (ft)**	**Primary Owner**	**Bridge Length (ft)**	**Bankfull Width (ft)**	**Bankfull Discharge (cfs)**	**Annual Chance Flood Event Equivalent[1] (%)**
Leydecker Road	413+05	Erie County	202	129	2,870	> 80%
US Route 20	513+57	NYSDOT	831	128	2,820	> 80%

[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.

4. CLIMATE CHANGE IMPLICATIONS

4.1 FUTURE PROJECTED DISCHARGE IN CAZENOVIA 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 21st 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 provides a summary of the projected future peak stream flows using the FEMA FIS peak discharges and 10% CRRA design multiplier.

Table 11. Cazenovia Creek Future Projected Peak Discharges

(Source: USGS 2016)						
			Peak Discharges (cfs)			
Location	**Drainage Area (mi^2)**	**River Station (ft)**	**10-percent**	**2-percent**	**1-percent**	**0.2-percent**
At confluence with Buffalo River	137.2	0+00	12,540	17,930	20,350	26,444
At abandoned railroad bridge	136.1	12+588	12,650	18,260	20,790	27,038
Upstream of confluence with Ebenezer Brook	134.2	19+314	12,936	18,590	21,120	27,588
Approximately 1,325 ft downstream of Big Tree Road (at Route 20A bridge)	116	932+75	10,890	14,080	16,280	18,480
Approximately 800 ft upstream of confluence with Cazenovia Creek West Branch	60	958+00	5,610	7,370	8,030	9,570
Approximately 800 ft upstream of confluence with Cazenovia Creek East Branch	56	966+00	5,280	6,710	7,370	8,910

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 0.9-ft 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 and future condition water surface elevations at the FEMA FIS discharge locations using USGS *StreamStats* and the CRRA 10% multiplier.

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

(Source: USGS 2016; USGS 2017; USACE 2019)						
			Water Surface Elevations (feet NAVD88) [1]			
Flooding Source and Location	Drainage Area (mi^2)	River Station (ft)	10-Percent	2-Percent	1-Percent	0.2-Percent
At confluence with Buffalo River	137.2	0+00	+ 0.94	+ 0.71	+ 0.74	+ 0.79
At abandoned railroad bridge	136.1	125+50	+ 0.6	+ 0.36	+ 0.39	+ 0.35
Upstream of confluence with Ebenezer Brook	134.2	196+00	+ 0.62	+ 0.45	+ 0.48	+ 0.57

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

5. FLOODING CHARACTERISTICS

5.1 FLOODING HISTORY

Flooding along Cazenovia Creek generally occurs in the late winter and early spring due to rapid snowmelt and spring rains. According to the effective FEMA FIS profile plot, the situation is compounded by restrictive bridges, which cause ice jams along the stream channel, and continued development in the floodplain, exposing greater numbers of assets to potential flood damages.

Particularly in the lower developed area of the basin in the City of Buffalo, flooding is often exacerbated by ice jams; discharges that typically would not induce damage result in severe flooding when in the presence of ice cover (USACE 1986). The USACE Cold Regions Research and Engineering Laboratory (CRREL) Ice Jams Database has recorded 118 ice jams on all watercourses within Erie County from 1929 and 2011, with 38 of those occurring on Cazenovia Creek. The Erie County Core Planning Group notes that one third of the 49 flooding events in Erie County from 1993 to 2002 were due to ice jams. Findings indicated that the most problematic area on Cazenovia Creek was near Cazenovia Park and the Stevenson Street bridge, both of which are a significant distance downstream from the ice-control structure upstream of Mill Road (URS 2015).

Most recently, in January of 2020 there was an ice jam near the I-90 bridge reported in the local news, but no associated flooding. In March 2004 the National Weather Service (NWS) reported a major ice jam on Cazenovia Creek near the I-90 bridge. The jam eventually broke free, progressing into Cazenovia Park and causing a sharp rise in downstream water level, forcing the Stevenson Street bridge to close. In December 2004 the NWS reported an ice jam on Cazenovia Creek between the Stevenson Street and Cazenovia Street bridges causing water to inundate Cazenovia Park (URS 2015). The basin is characterized by relatively steep terrain causing rapid runoff. The upper basin experiences little flooding and minimal damages due to the undeveloped nature of the floodplain. The worst flooding in the area typically occurs in the lower portion of the basin, from just downstream of the Cazenovia Street bridge in the City of Buffalo, to just upstream of the Mill Road Bridge in the Town of West Seneca (USACE 1986).

FEMA FIRMs are available for Cazenovia Creek from FEMA. Figures 5-1 and 5-2 display the floodway and 1- and 0.2% annual chance flood event boundaries for Cazenovia Creek as determined by FEMA for the City of Buffalo and Town of West Seneca, respectively. The maps indicate that flooding generally occurs in the upstream portions of West Seneca. Generally, the areas shown to be within the 100-year floodplain remain largely undeveloped, or well suited for floodplain development, for example, the Cazenovia Park Golf Course, and West Seneca Soccer Complex. Downstream near the confluence with the Buffalo River, the maps indicate some residential flooding during the 500-year event (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.

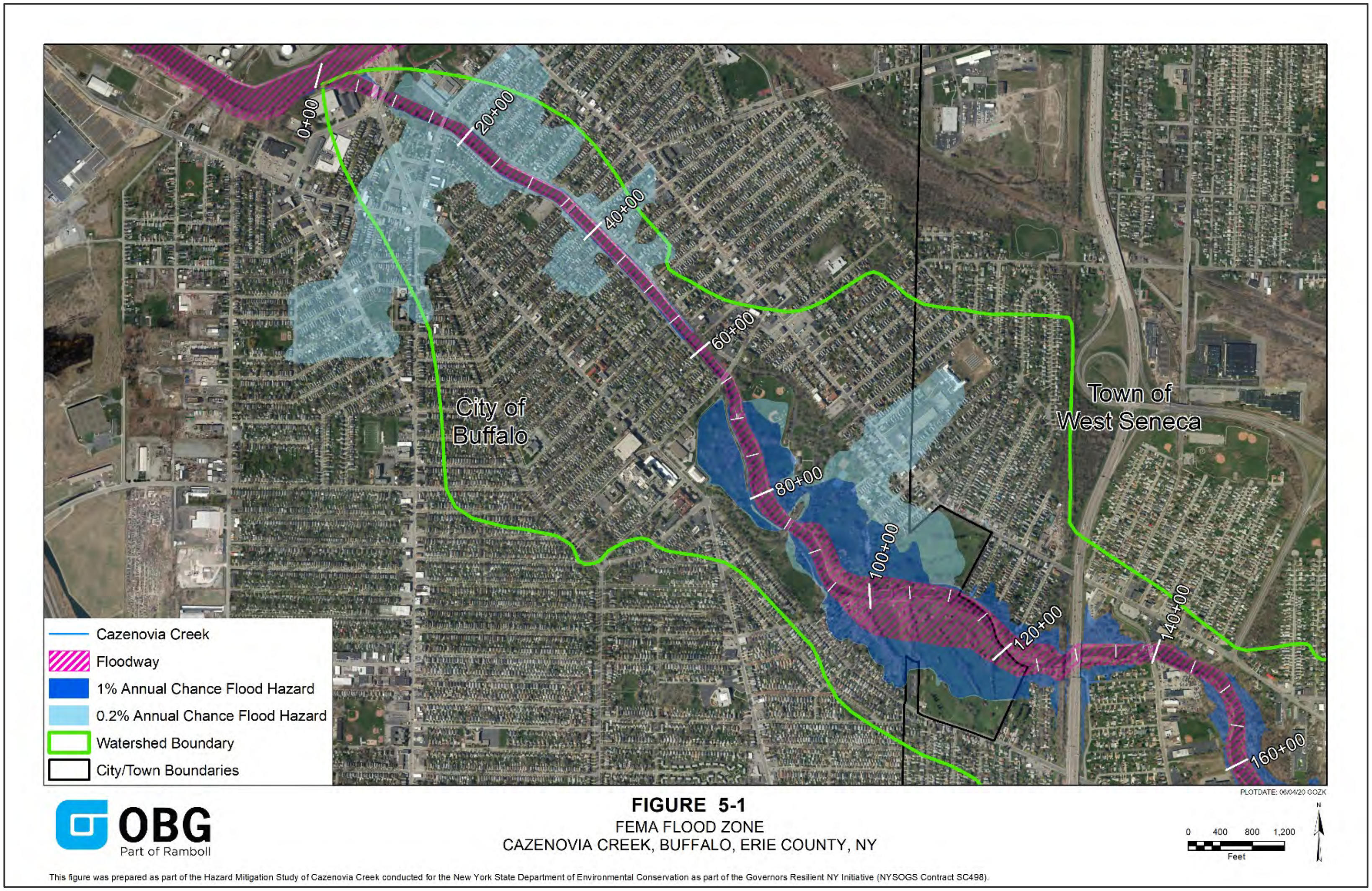

Figure 5-1. FEMA Flood Zones, Cazenovia Creek, City of Buffalo, Erie County, NY.

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

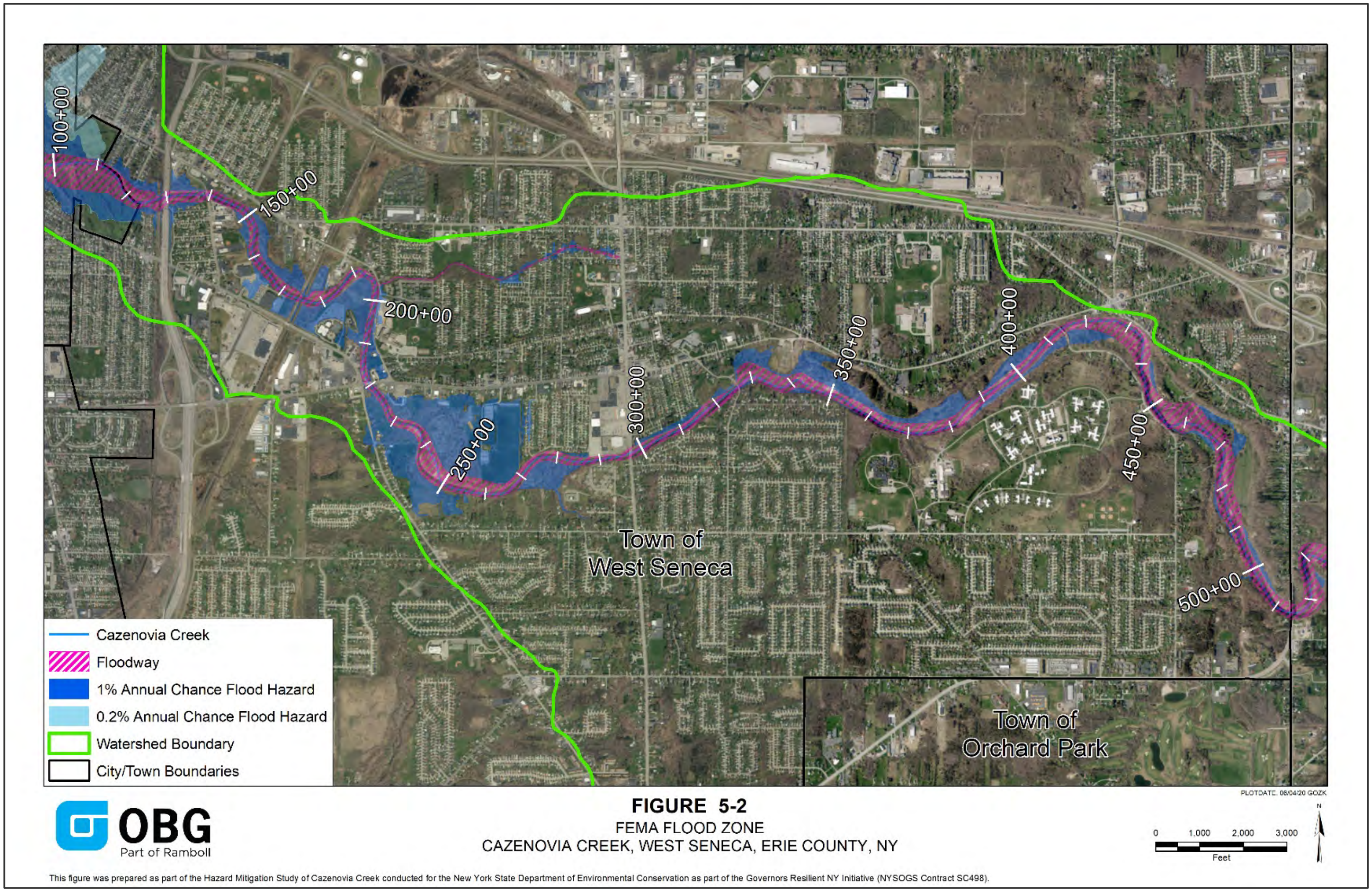

Figure 5-2. FEMA Flood Zones, Cazenovia Creek, Town of West Seneca, Erie County, NY.

*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 Cazenovia 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% 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 Cazenovia 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 2016b).

Hydraulic and Hydrologic modeling of Cazenovia Creek in the City of Buffalo and Town of West Seneca were completed by FEMA in 2007 and 1990, respectively. This model covered roughly half of the target area; thus, an updated 1-D HEC-RAS model was developed to include the remaining upstream portion of the target area 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 HEC-RAS software
- ESRI ArcMap 10.7 with the HEC-GeoRAS extension GIS software (ESRI 2019)

The hydraulics model was developed for Cazenovia Creek beginning at the confluence of the Buffalo River (river station 0+00) and extending upstream to the Southgate Plaza on Union Road (river station 294+25).

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:

City of Buffalo:

- Increase size of Stevenson Street bridge opening
- Increase size of Warren Spahn Way bridge opening

Town of West Seneca:

- Flood bench near Gossel's Island
- Ice piers and flood bench near Gossel's Island
- Increase size of Ridge Road bridge opening
- Flood bench at river station 150+00
- Flood bench at river station 190+00
- Tree and shrub clearing along river station 190+00

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; namely floodplain benches and associated stabilization measures.

Where recent construction cost data was not readily available, RSMeans CostWorks 2019 was used to determine accurate and timely information (RSMeans Data Online 2019). Additionally, a 2016 USACE report focused on flood mitigation measures in the

Lexington Green area (USACE 2016c) was used for pricing information for some of the mitigation alternatives. Costs were adjusted for inflation and verified against current market conditions and trends.

For mitigation alternatives where increases in bridge sizes were recommended, bridge 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), applications to FEMA, etc. 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

The Cazenovia Creek watershed is susceptible to ice jam formation and consequent ice-jam related flooding. Since 2000, there have been 24 ice-jam events recorded in the USACE ice-jam data base on Cazenovia Creek (CRREL 2020). The most recent ice-jam event on Cazenovia Creek occurred on January 22, 2020, when unusually cold temperatures followed a period of warm temperatures, which caused snow and ice to flow resulting in the ice jam stopping in the Town of West Seneca and City of Buffalo.

Based on historical flood reporting’s found on news media on the internet and through public outreach, the City of Buffalo and Town of West Seneca were identified to be the most adversely affected communities by wintertime flooding in the Cazenovia Creek basin. Ice-jam flooding on Cazenovia Creek occurs primarily in the following locations:

- City of Buffalo at confluence with Buffalo Creek
- City of Buffalo at Stevenson Street bridge
- Town of West Seneca at I-90

Based on modeling results, stakeholder input, and information found on various sources of news media, it appears that ice jam issues along the lower, more developed portions of Cazenovia Creek tend to be largely influenced by ice jamming on the Buffalo River. Cazenovia Creek flows into the Buffalo River after flowing through a long straight concrete section of creek through the City of Buffalo. When ice jams form on the Buffalo River, ice flowing downstream on Cazenovia Creek becomes jammed at the confluence and begins to form an ice jam into the Cazenovia Creek. When the ambient air temperature is cold enough, the temperature of the concrete exposed to the air will drop less than that of the water flowing through the creek, starting to cool the water by acting as a conducting element between water and cold air at below freezing temperature. This phenomenon will tend to generate more ice formation in the concrete lined channel section contributing to the ice jam formation at the downstream confluence with the Buffalo Creek. Therefore, the jamming at the confluence, paired with the long length of concrete channel largely contributes to ice-jam related issues along this portion of Cazenovia Creek.

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 Cazenovia Creek were identified as high-risk flood areas in the City of Buffalo and Town of West Seneca.

6.4.1 High Risk Area #1: Concrete-lined Channel Section within City of Buffalo

High Risk Area #1 is the section of concreted-lined channel from Cazenovia Street to the confluence with Buffalo River. Ice jamming often occurs on the Buffalo River, and thus Cazenovia Creek often experiences ice jamming due to the blockage at the confluence. During cold winter ambient air temperatures, the concrete lining on the creek becomes colder than the water due to the exposure of the concrete lining to the ambient air, contributing to more ice formation. These effects of the concrete lining associated with the ice jamming along the Buffalo River contribute to the ice jamming often seen along Cazenovia Creek. Additional ice generation in the creek thickens the ice cover and ice jam and increases the effective flow roughness to the flow. Increase in roughness will increase water levels making it more vulnerable to flooding.

Within this section, the Stevenson Street bridge is often associated with reports of ice jams according to the local media (Gibas 2018; Arena et al. 2019). The effective FIRMs show that there is no flooding due to the 1% annual chance flood event throughout this concrete lined section. The low chord of the Stevenson Street bridge is approximately equal to the 2% annual chance flood event water surface elevation.

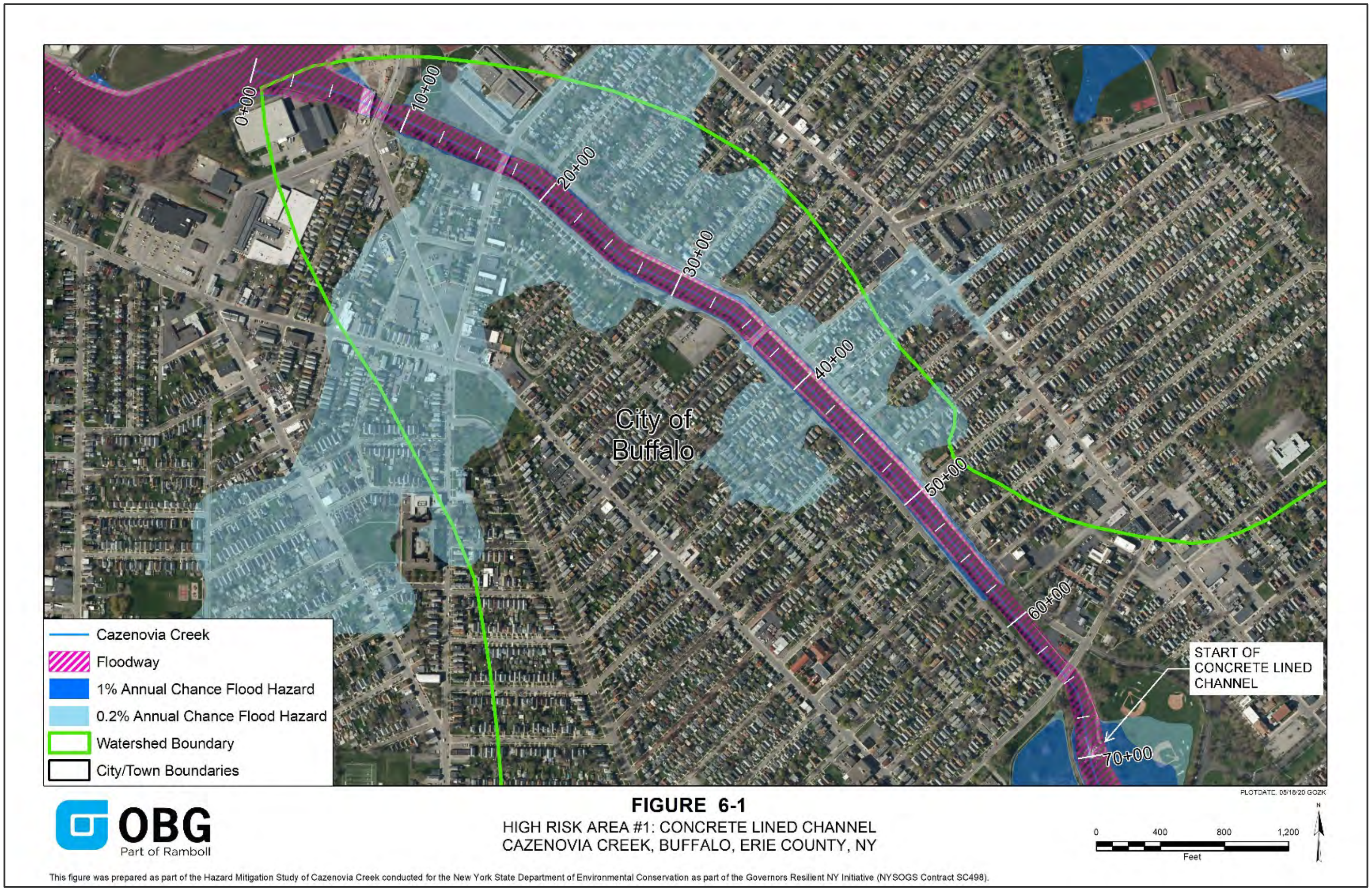

Figure 6-1. High Risk Area #1: Concrete-lined Channel Section within City of Buffalo.

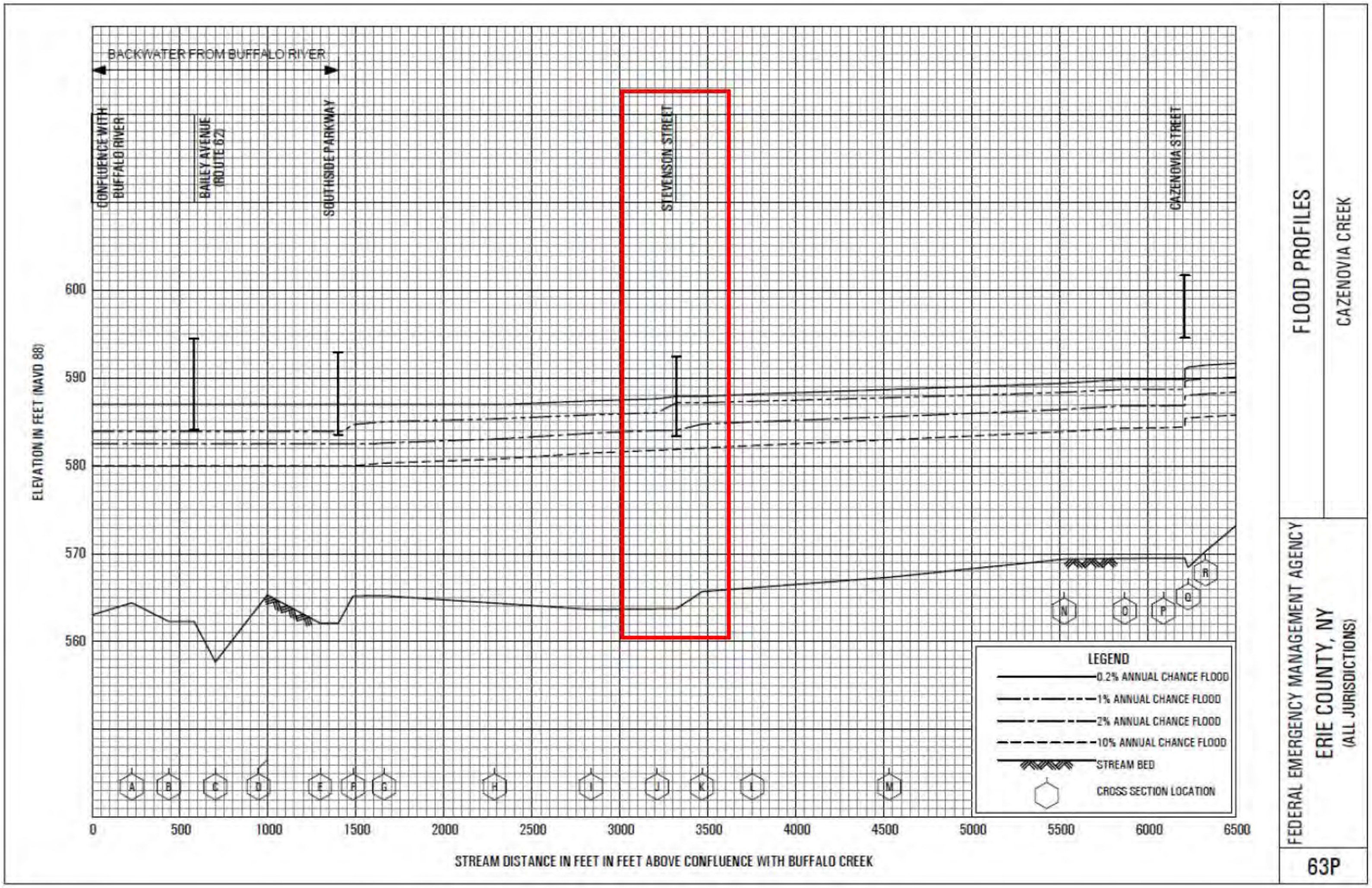

Figure 6-2. FEMA FIS profile for the Stevenson Street bridge crossing.

6.4.2 High Risk Area #2: Gossel's Island – Shoal Formation

High Risk Area #2 is the area of Gossel's Island, upstream of the Ridge Road bridge in the Town of West Seneca. Community feedback during the engagement session revealed that there have been reports of ice shoal formation due to the island and stream geometry (NYSDEC 2019a). The topography in this area is very low; the effective FEMA FIRMs show the 100-year floodplain spreading out much wider than any other nearby areas along the stream. This widening of the floodplain results in much lower stream velocities, which during winter conditions, is favorable for ice formation.

Gossel's Island is within the limits of the Clearing & Snagging Project sponsored by the Town of West Seneca. The right channel has historically provided additional storage acting as an overflow channel during high discharge or ice jam events. However, sediment aggradation in Gossel's Island and the right channel have reduced the additional storage capacity in the area and increased flood risk to adjacent and upstream areas.

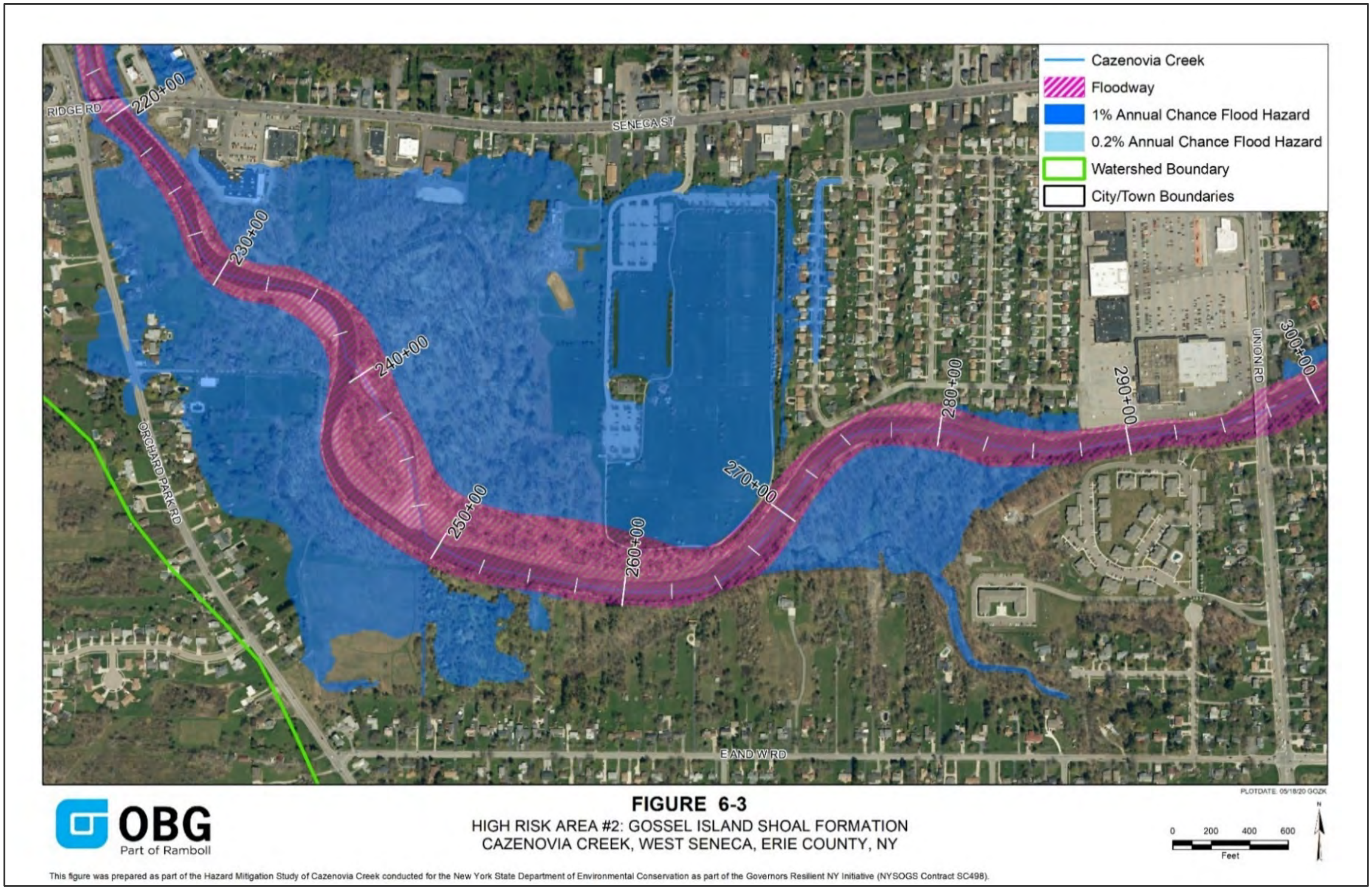

Figure 6-3. High Risk Area #2: Gossel's Island Shoal Formation along Cazenovia Creek in West Seneca.

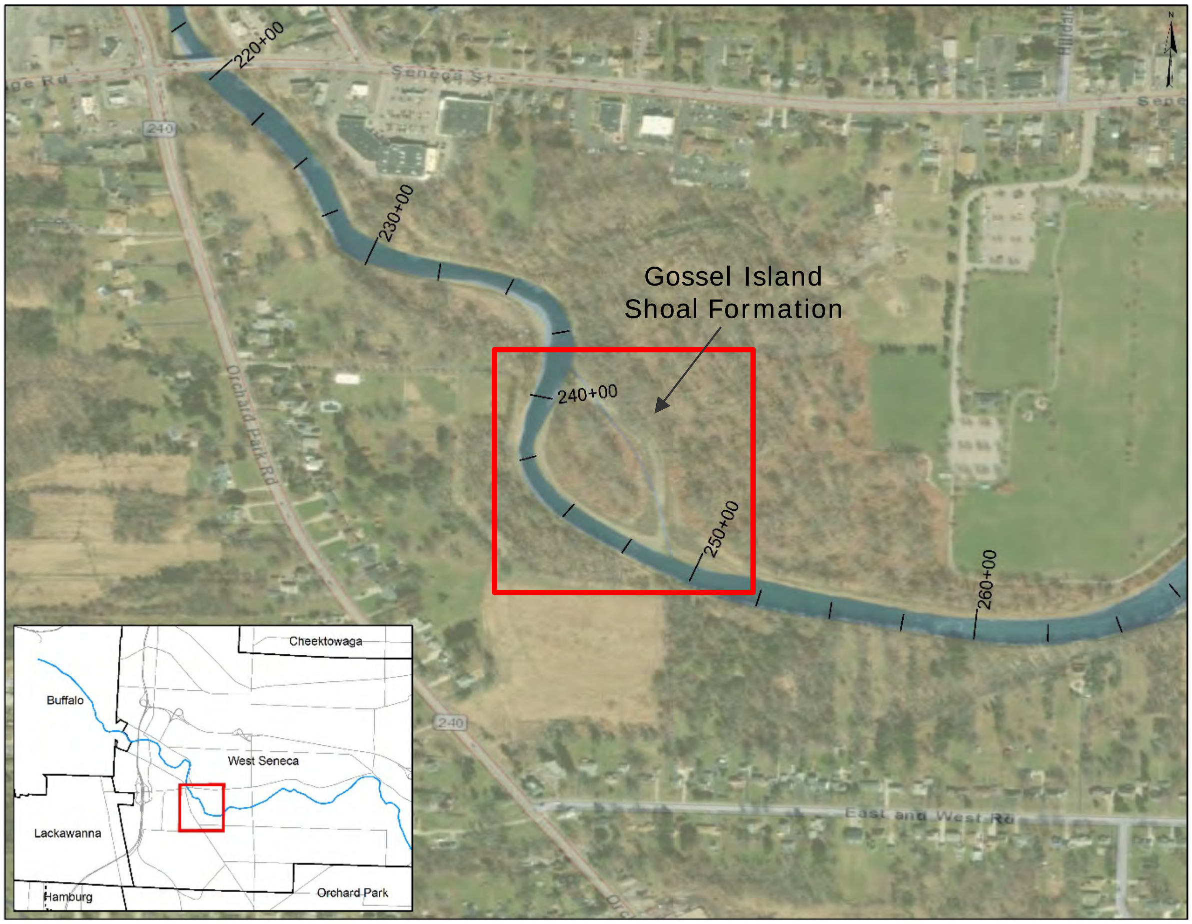

Figure 6-4. Gossel's Island Shoal Formation along Cazenovia Creek in West Seneca.

6.4.3 High Risk Area #3: Railroad Bridges Near Western New York Medical Park

High Risk Area #3 is the area near the pair of railroad bridges downstream of Western New York Medical Park. The effective FEMA FIRMs show these bridges as a constriction point of flow. Immediately upstream of the bridges is a near 180° bend in the stream channel.

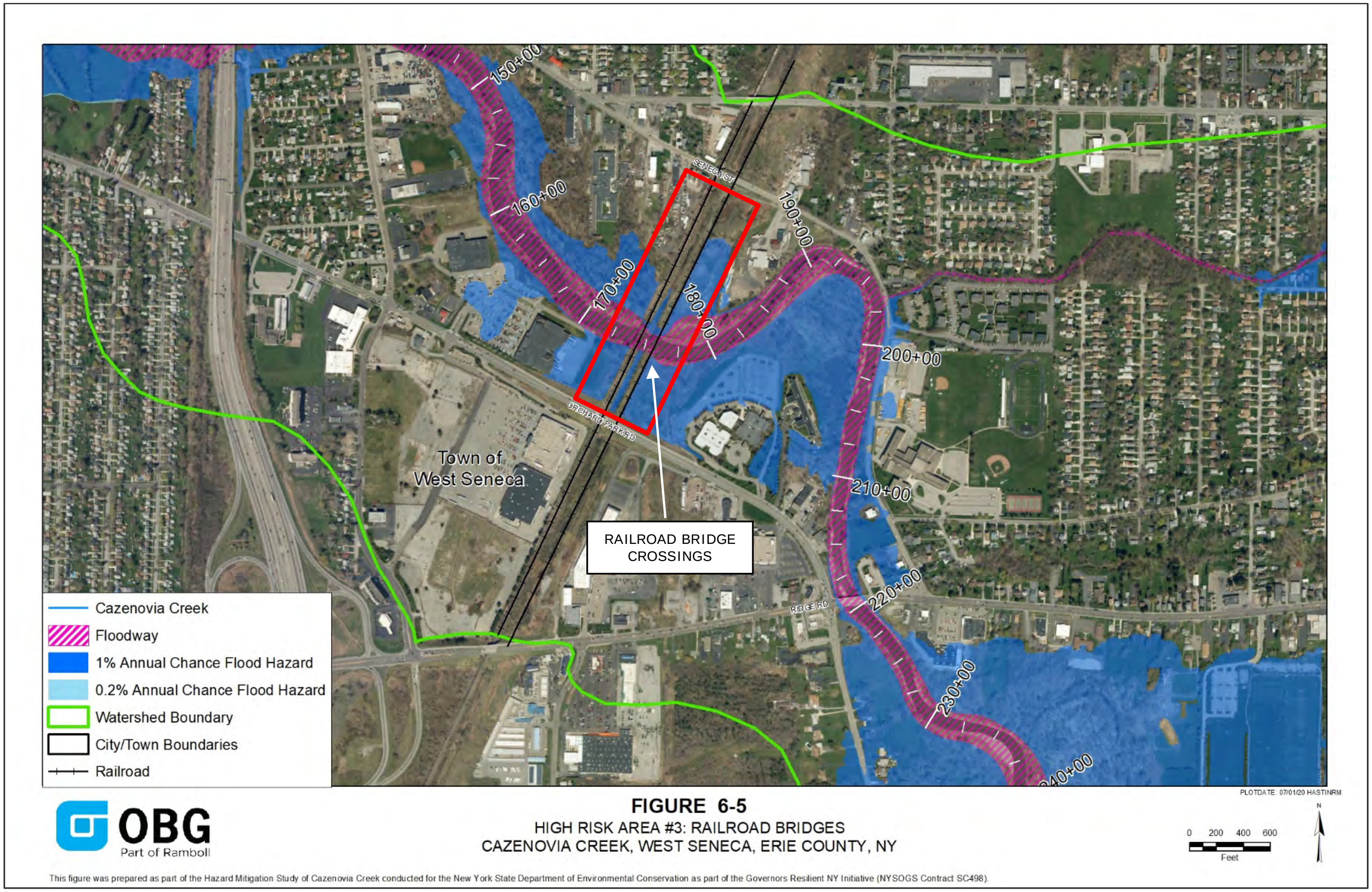

Figure 6-5. High Risk Area #3: Railroad Bridges Near Western New York Medical Park.

7. MITIGATION ALTERNATIVES

7.1 HIGH RISK AREA #1

7.1.1 Alternative #1-1: Increase Stevenson Street Bridge Opening

This measure is intended to address issues within High Risk Area #1 by providing a vertical height increase in the Stevenson Street bridge opening located at river station 33+35. Sight distance was not analyzed at this stage of conceptual project planning; line of sight analysis will need to be considered if this alternative is advanced further in the design process. Due to the concrete lining and density of nearby homes, a widening scenario would not likely be practical, thus leaving the option of a vertical height increase in the form of an arch span bridge. According to the FEMA FIS and base condition HEC-RAS model, the Stevenson Street bridge is unable to pass the NYSDOT recommended 2% annual chance flood plus required 2-ft of freeboard with the low chord elevation roughly equal to the 2% annual chance flood event water surface elevation. While the effective FIRMs do not show out of channel flooding through the entire concrete lined section, ice jam flooding has been reported to be associated with the Stevenson Street bridge.

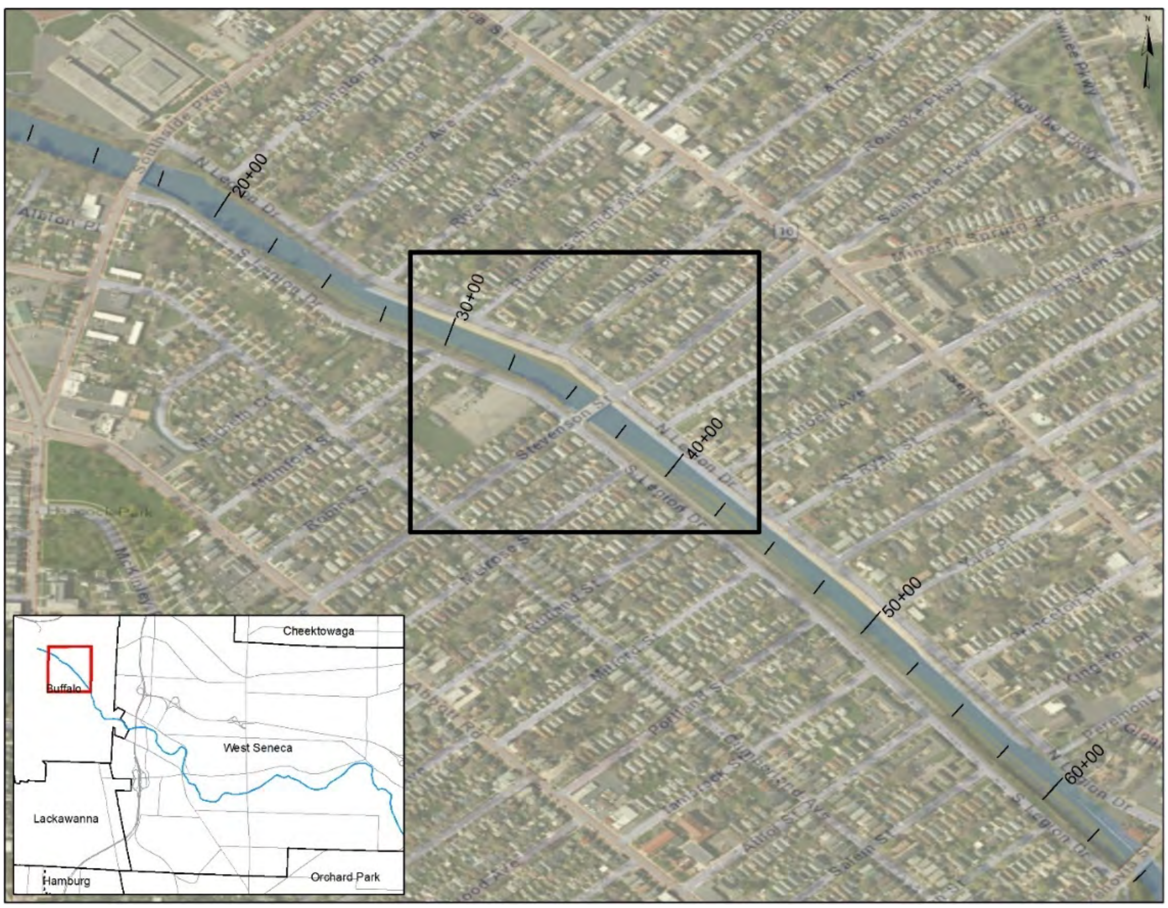

Figure 7-1. Location map for Alternative #1-1: Increase Stevenson Street Bridge Opening.

The proposed condition modeling confirmed that increasing the vertical height of the Stevenson Street bridge will offer a flood reduction benefit in both open water, and ice jam conditions. During open water conditions, a 4-ft vertical increase in the bridge opening results in a water surface reduction of approximately 1.1-ft at the upstream bridge face.

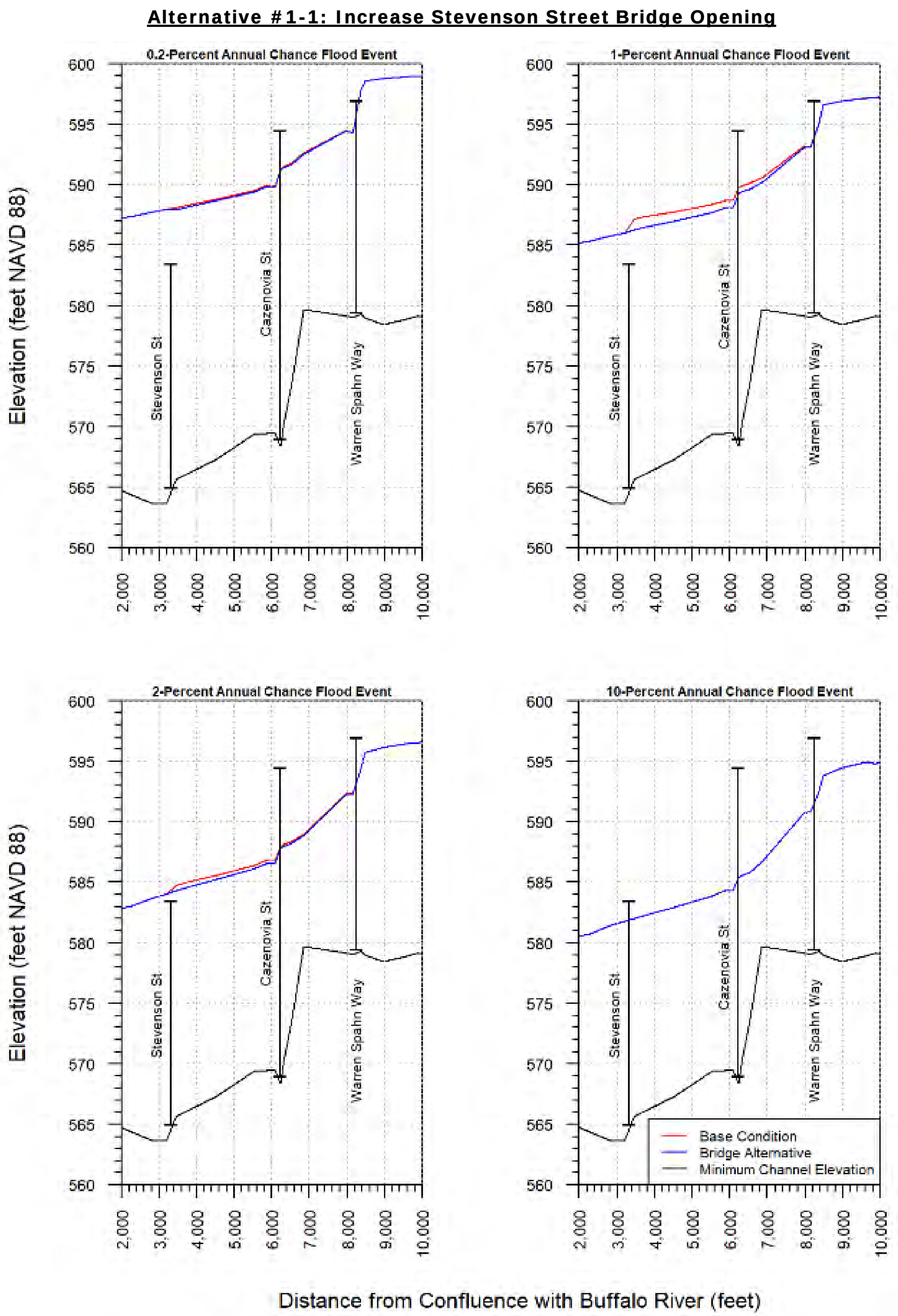

Figure 7-2. HEC-RAS model simulation output results for Alternative #1-1.

To assess the influence of ice jams on the Stevenson Street bridge, an ice cover simulation was performed with a 1-ft thickness ice cover. This simulation was intended to mimic the effects of a mild winter ice jam, which would reduce the cross-sectional area of the flow, and increase the in-channel roughness. In the presence of ice, the proposed condition modeling shows an approximately 0.36-ft reduction in water surface elevation due to the vertical height increase of the bridge while maintaining flow within the channel.

The potential water surface elevation reduction benefits of this alternative, for open water conditions, would extend upstream to the Warren Spahn Way bridge.

The Rough Order of Magnitude cost for this alternative is: $4.7 million

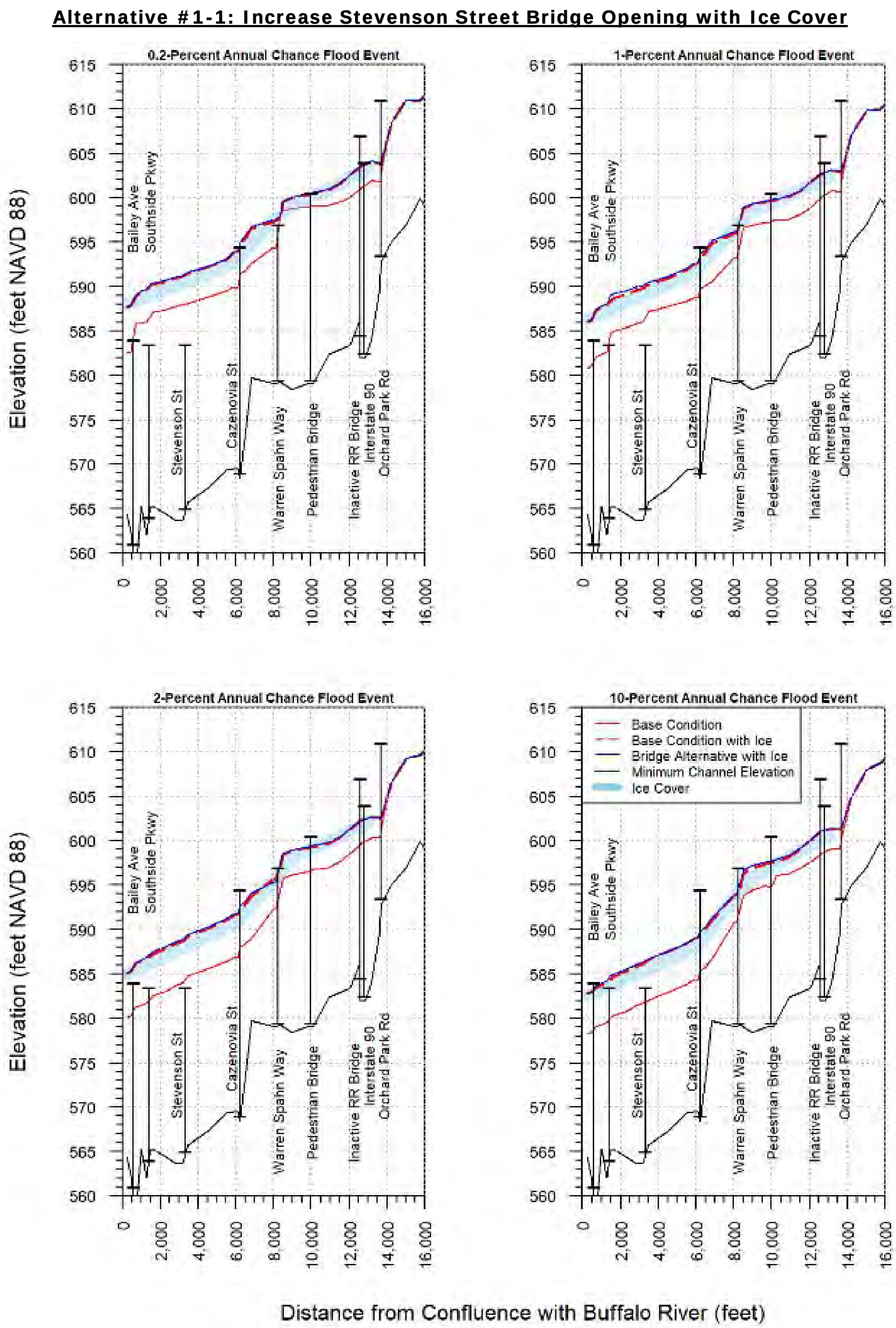

Figure 7-3. HEC-RAS ice-cover model simulation output results for Alternative #1-1.

7.1.2 Alternative #1-2: Increase Warren Spahn Way Bridge Opening

This measure is intended to address issues within High Risk Area #1 by providing a 50-ft width increase in the Warren Spahn Way bridge opening located at river station 82+53. According to the FEMA FIS and base condition HEC-RAS model, the Warren Spahn Way bridge meets the NYDOT guidelines for freeboard with the low chord elevation roughly 5-ft above the 2% annual chance flood event water surface elevation. However, the bridge opening is smaller than the bankfull and flood flow width so the bridge acts to constrict flow during high flow events causing backwater. The effective FIRMs show the bridge as a constriction point for flow. Upsizing the bridge by widening the opening would reduce backwater flooding in Cazenovia Park, and likely reduce the potential for ice jams to get hung up at the constriction point due to the bridge opening.

Figure 7-4. Location map for Alternative #1-2: Increase Warren Spahn Way Bridge Opening.

The proposed condition modeling confirmed that increasing the width of the Warren Spahn Way bridge will offer a flood reduction benefit in both open water, and ice jam conditions. Open condition water surface reductions were limited to higher flow events, specifically the 0.2% annual chance event. During open water conditions, a 50-ft width increase in the bridge opening results in a water surface reduction of approximately

3.7-ft at the upstream bridge face for the 0.2% annual chance flood event, while the water surface is unchanged for lesser events.

Alternative #1-2: Increase Warren Spahn Way Bridge Opening

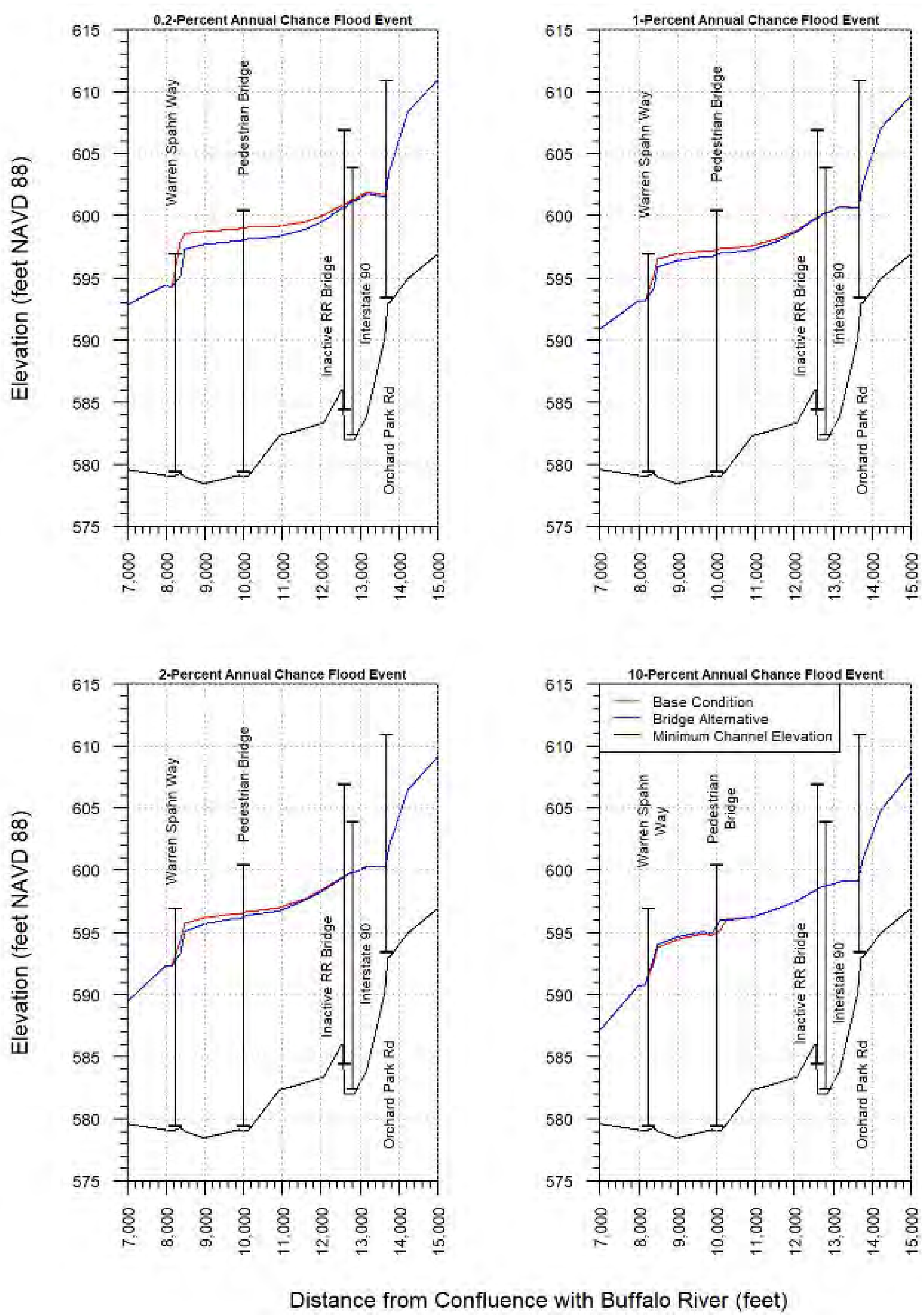

Figure 7-5. HEC-RAS model simulation output results for Alternative #1-2.

To assess the influence of ice jams on the Warren Spahn Way bridge, an ice cover simulation was performed with a 1-ft thickness ice cover. This simulation was intended to mimic the effects of a mild winter ice jam, which would reduce the cross-sectional area of the flow, and increase the in-channel roughness. In the presence of ice, the proposed condition modeling shows an approximately 0.5' reduction in water surface elevation due to the 50-ft width increase of the bridge.

The potential water surface elevation reduction benefits of this alternative, for open water conditions, would extend upstream of the Cazenovia Park Golf Course suspension bridge. The area of major benefit from this project would be the immediately adjacent park and golf course.

The Rough Order of Magnitude cost for this alternative is $5.9 million.

Alternative #1-2: Increase Warren Spahn Way Bridge Opening with Ice Cover

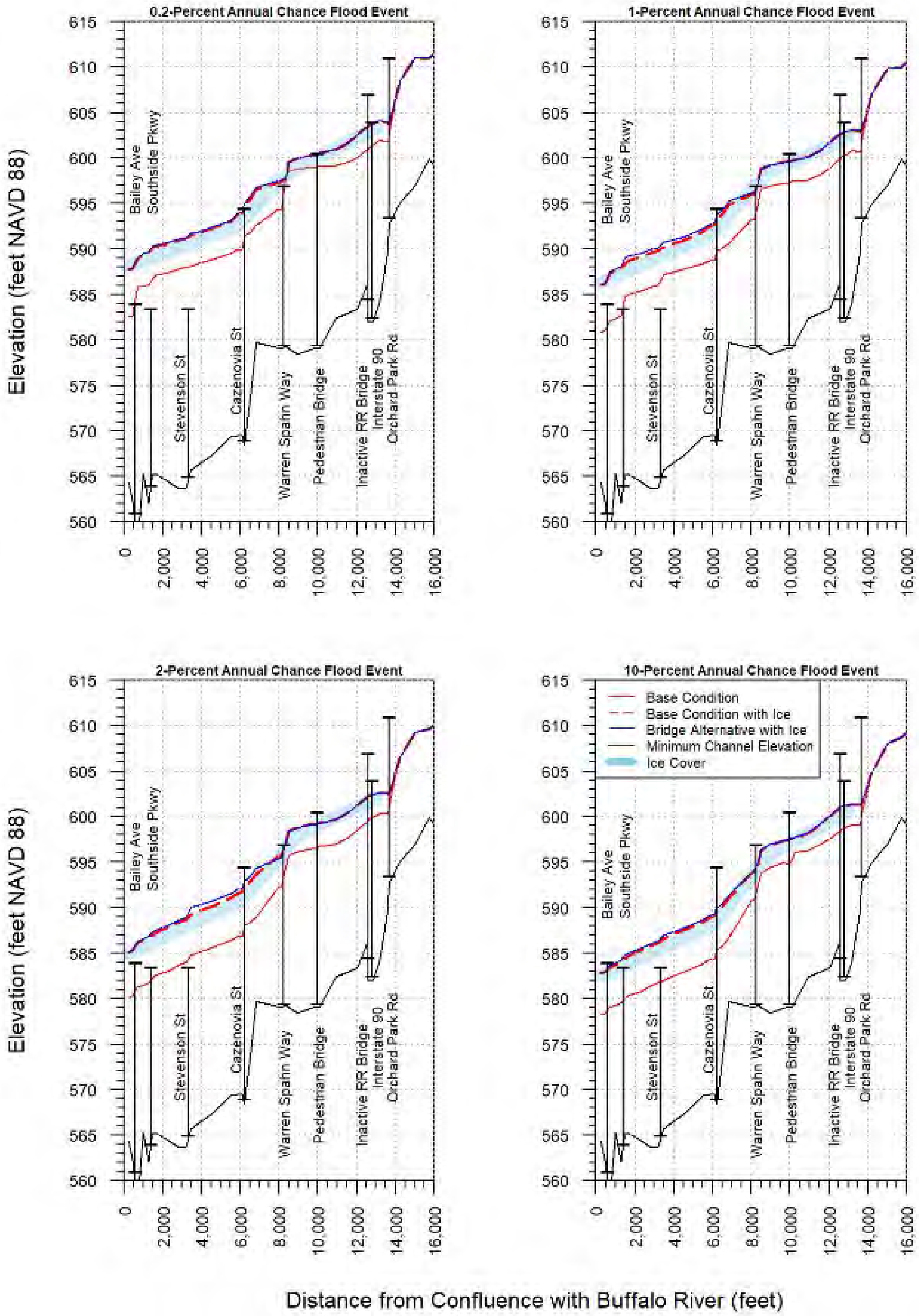

Figure 7-6. HEC-RAS ice-cover model simulation output results for Alternative #1-2.

7.2 HIGH RISK AREA #2

7.2.1 Alternative #2-1: Flood Bench Near Gossel's Island

This measure is intended to address issues within High Risk Area #2 by providing additional flood storage and eliminating ice shoal formation which has been reported to occur at Gossel's Island. A flood bench could be located anywhere between river stations 230+00 and 260+00. By creating a large engineered flood bench, ice shoal formation in the main channel will be minimized. This strategy would require a phased approach, with three individual flood benches being constructed. This strategy would require the excavation of approximately 28 acres of land along the right bank of the creek adjacent to the West Seneca Soccer Complex, split into three smaller benches of 10, 11 and 7 acres, respectively for alternatives A, B and C. The flood bench is within the FEMA designated Special Flood Hazard Area (SFHA) or Zone AE, which are areas subject to inundation by the 1% annual chance flood event determined by detailed methods where Base Flood Elevations (BFEs) are shown, and mandatory flood insurance purchase requirements and floodplain management standards apply. Appendix E depicts a flood mitigation rendering of a flood bench illustrating before and after landscape features.

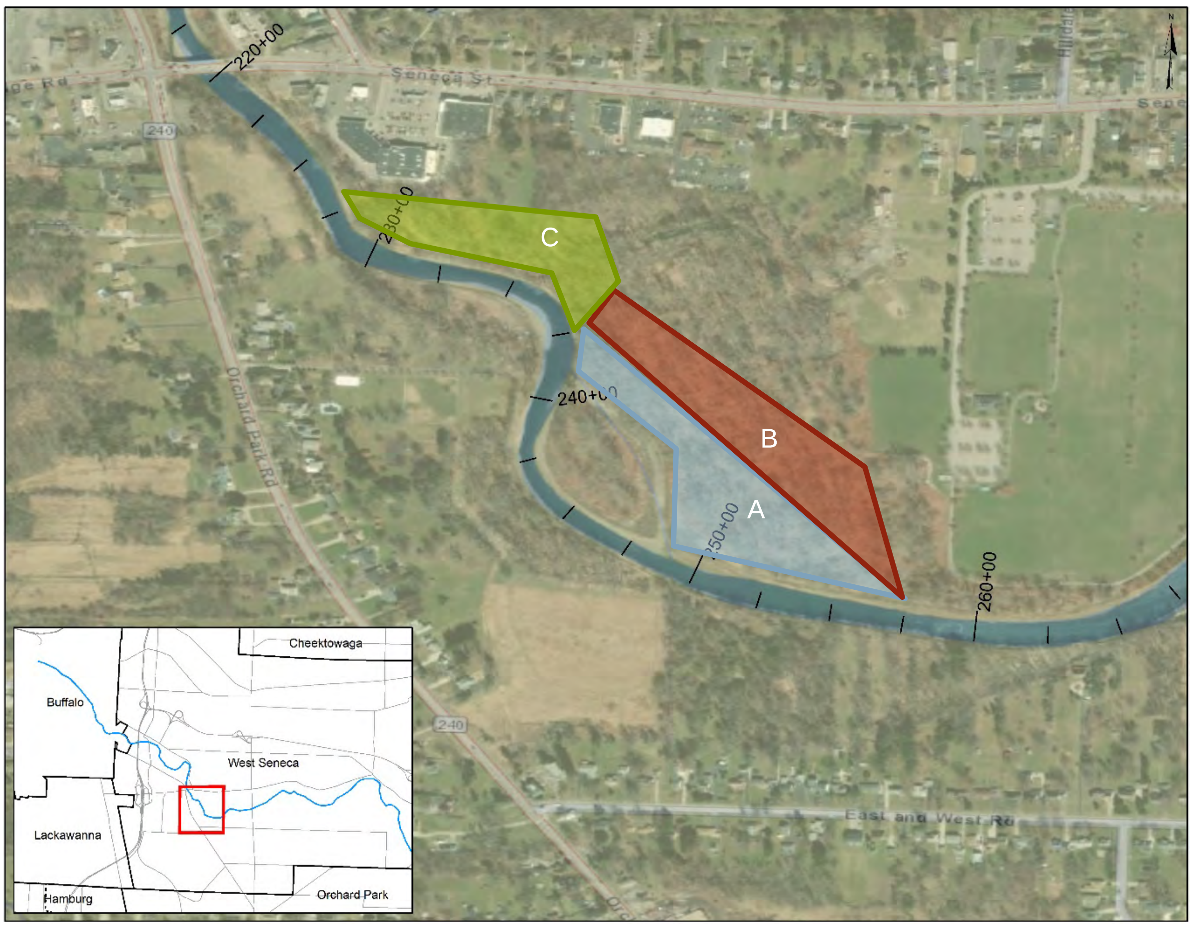

Figure 7-7. Location map for Alternative #2-1: Flood Bench Near Gossel's Island.

The proposed condition modeling confirmed that the creation of a flood bench in the area of Gossel's Island will offer a flood reduction benefit in open water conditions. During open water conditions, this alternative offers up to a 0.9-ft reduction in water surface elevation for the 1% annual chance flood event, with all three benches constructed.

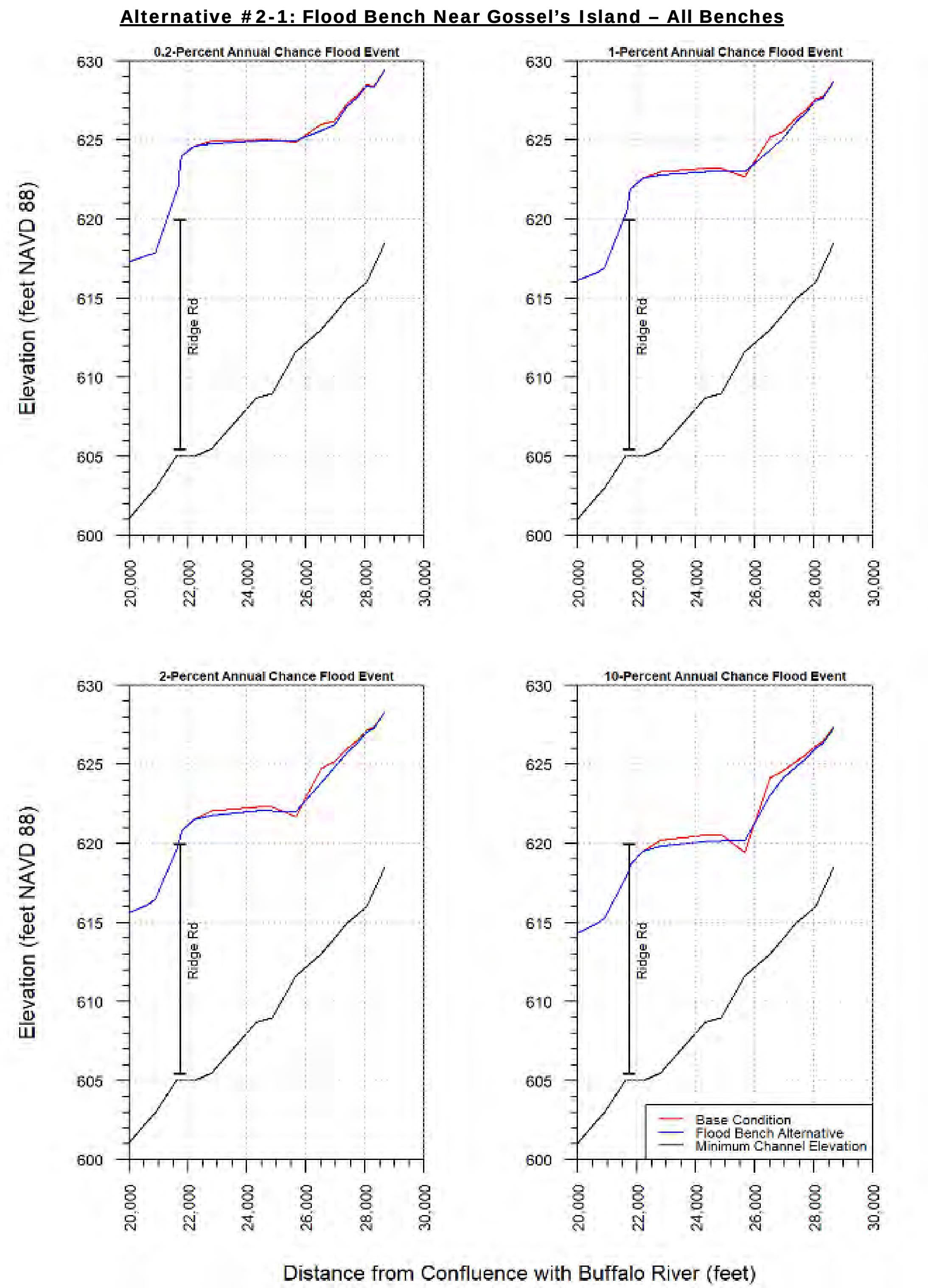

Figure 7-8. HEC-RAS model simulation output results for Alternative #2-1 All Benches.

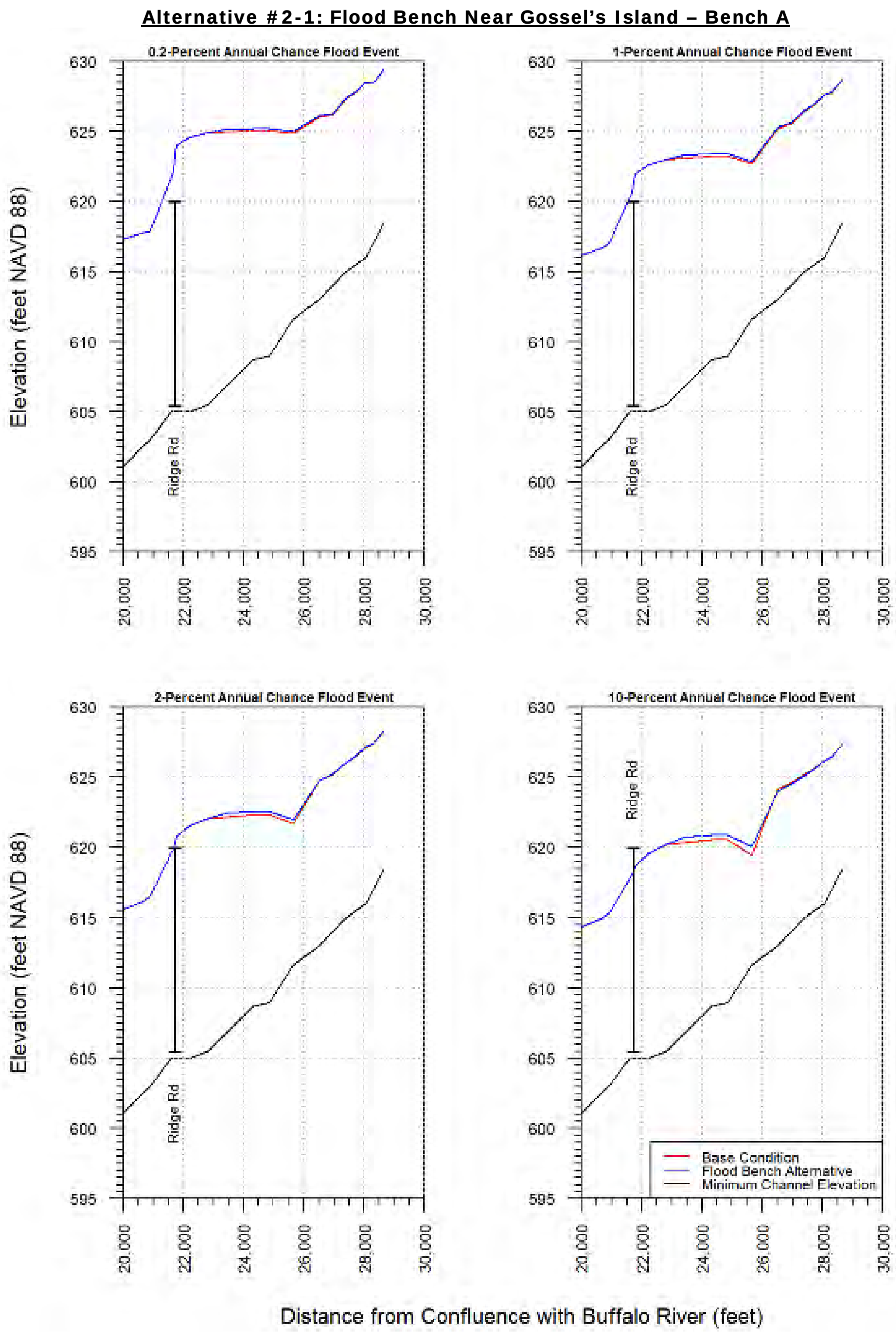

Figure 7-9. HEC-RAS model simulation output results for Alternative #2-1 Bench A.

Alternative #2-1: Flood Bench Near Gossel's Island – Bench B

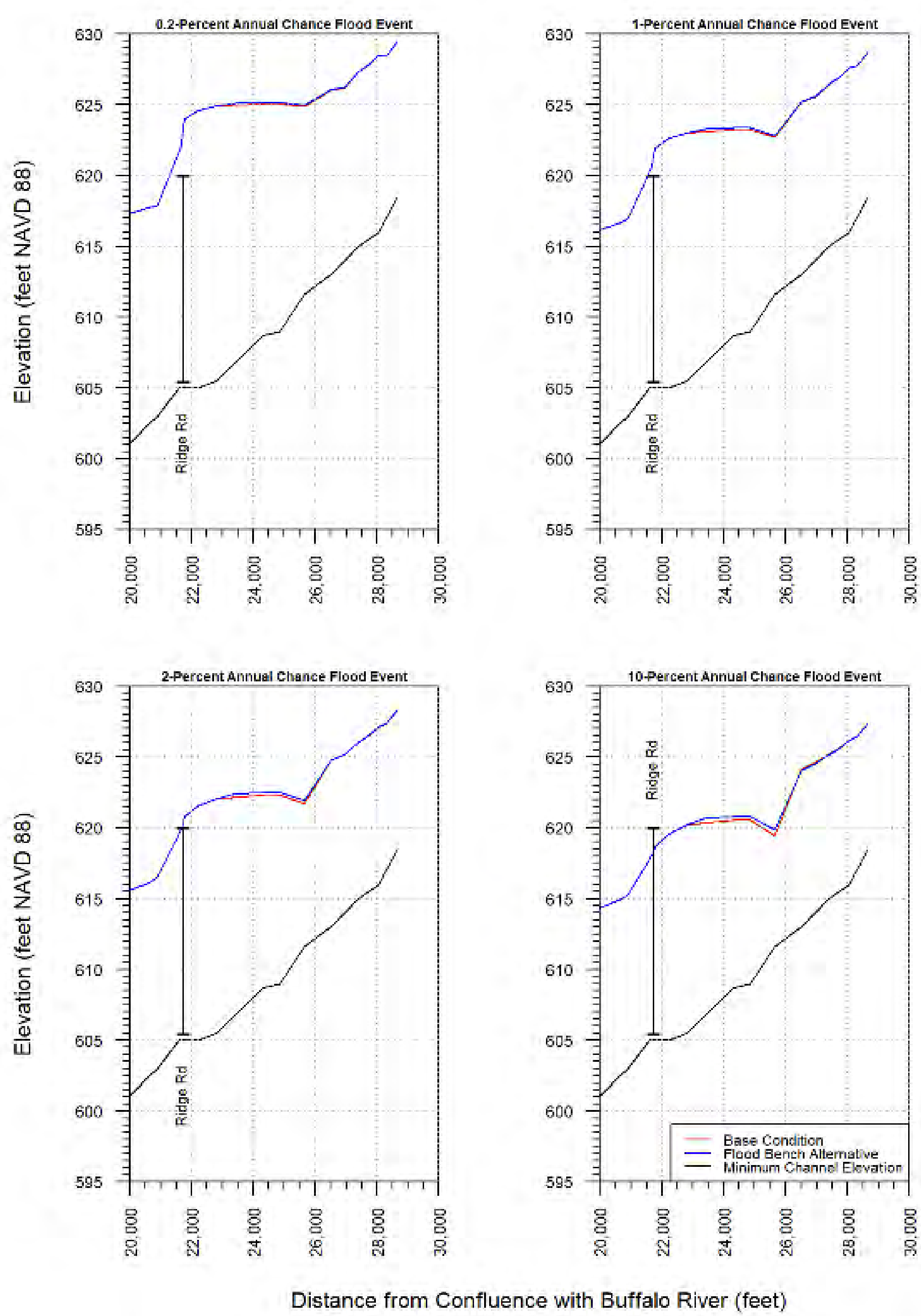

Figure 7-10. HEC-RAS model simulation output results for Alternative #2-1 Bench B.

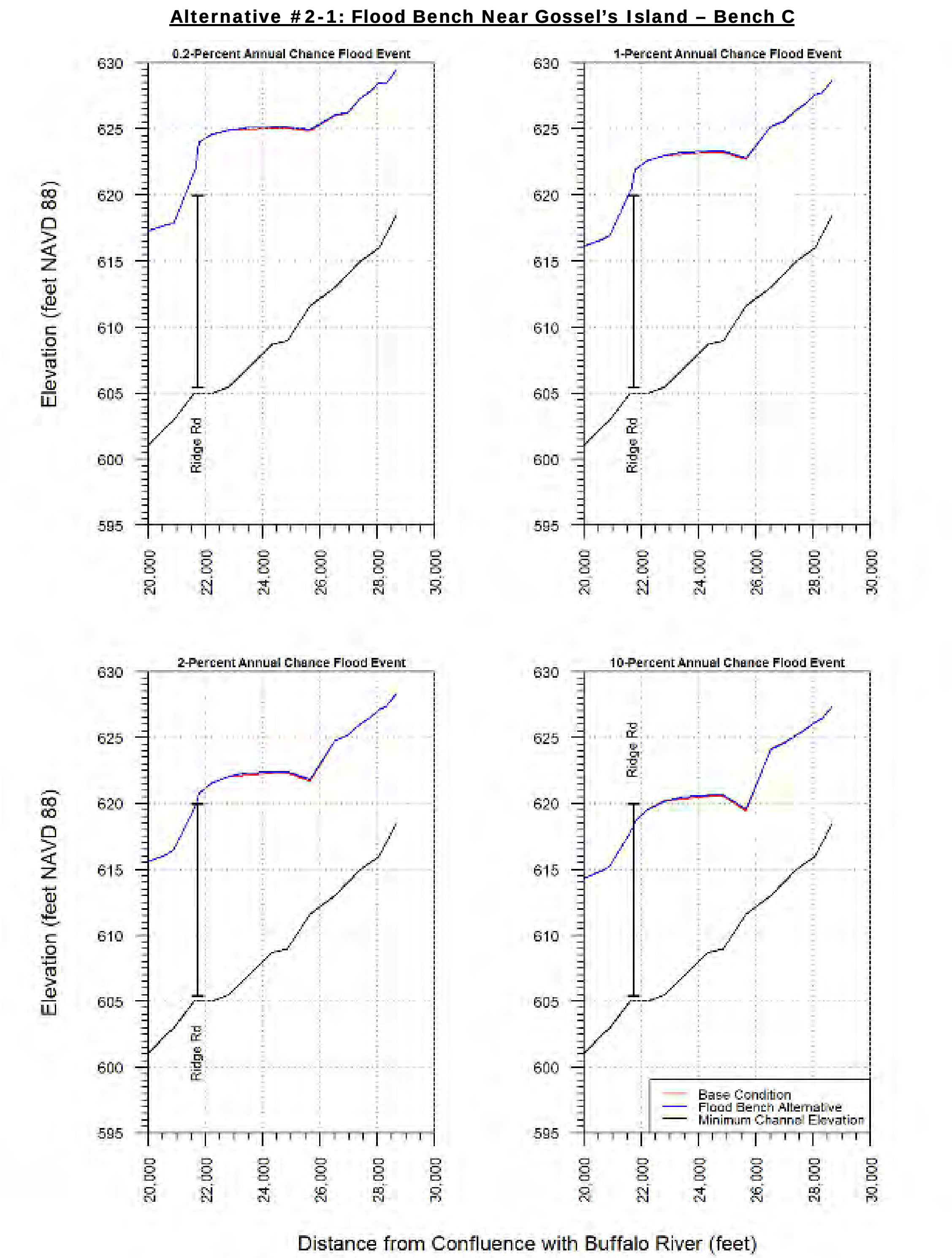

Figure 7-11. HEC-RAS model simulation output results for Alternative #2-1 Bench C.

To assess the influence of ice jams on the area of Gossel's Island, an ice cover simulation was performed with a 1-ft thickness ice cover. This simulation was intended to mimic the effects of a mild winter ice jam, which would reduce the cross-sectional area of the flow, and increase the in-channel roughness. In the presence of ice, the proposed condition modeling shows minimal reduction of water surface elevation for the 10-year flood event.

The Rough Order of Magnitude costs for this alternative are:

Bench A: $3 million

Bench B: $3.3 million

Bench C: $2.1 million

Total for all benches: $8.4 million

Alternative #2-1: Flood Bench Near Gossel's Island with Ice Cover – All Benches

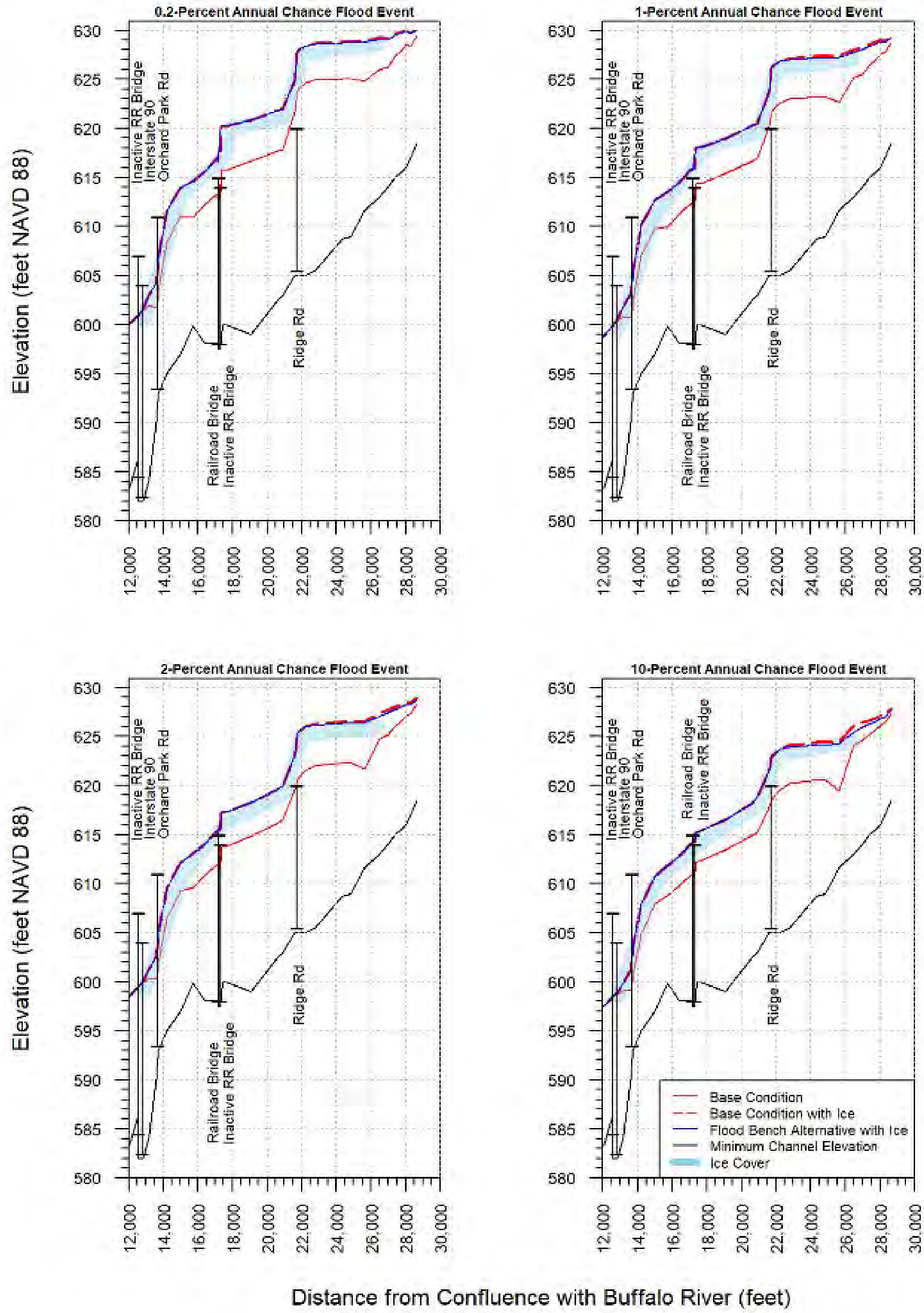

Figure 7-12. HEC-RAS ice-cover model simulation output results for Alternative #2-1 All Benches.

Alternative #2-1: Flood Bench Near Gossel's Island with Ice Cover – Bench A

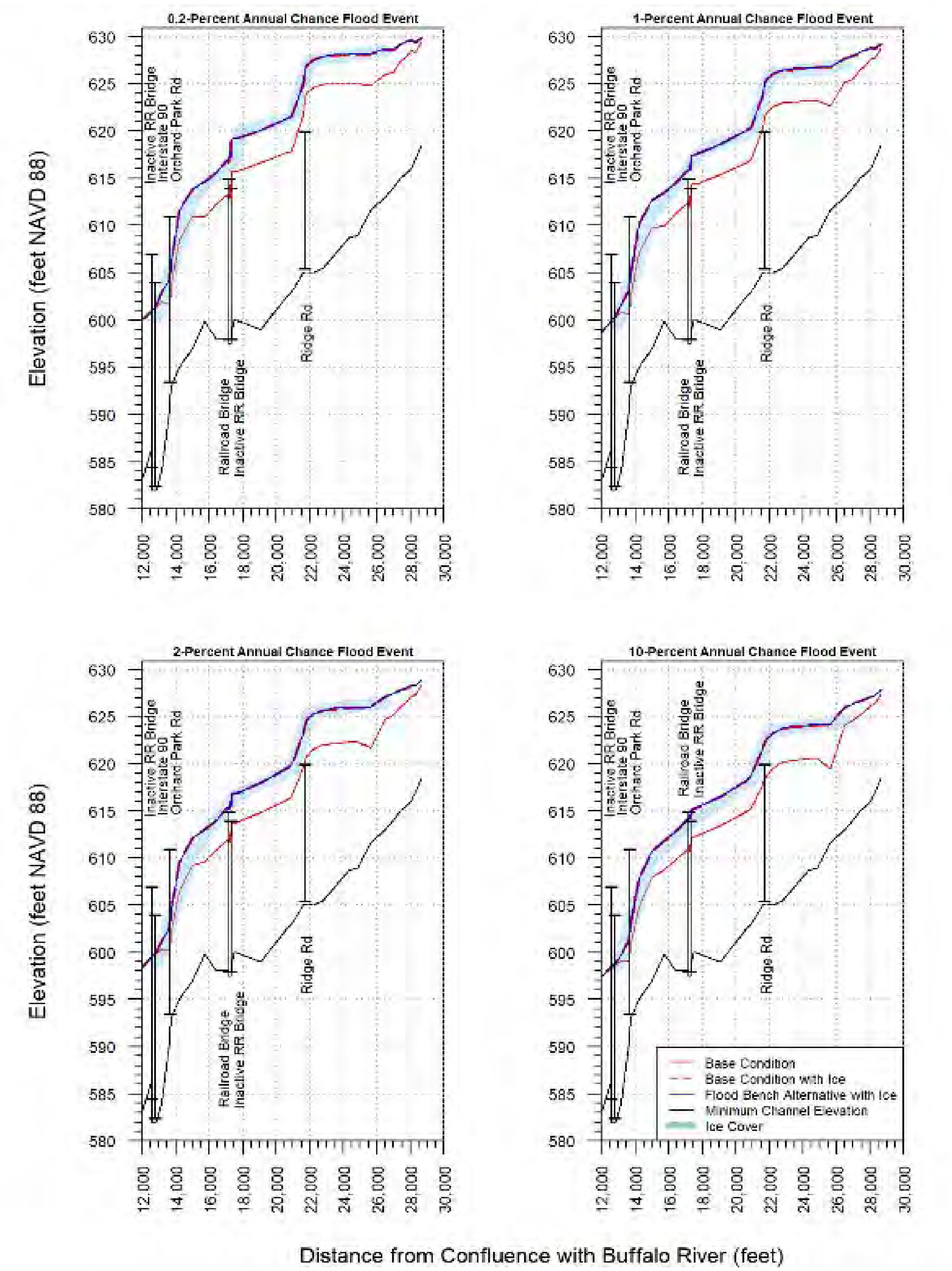

Figure 7-13. HEC-RAS ice-cover model simulation output results for Alternative #2-1 Bench A.

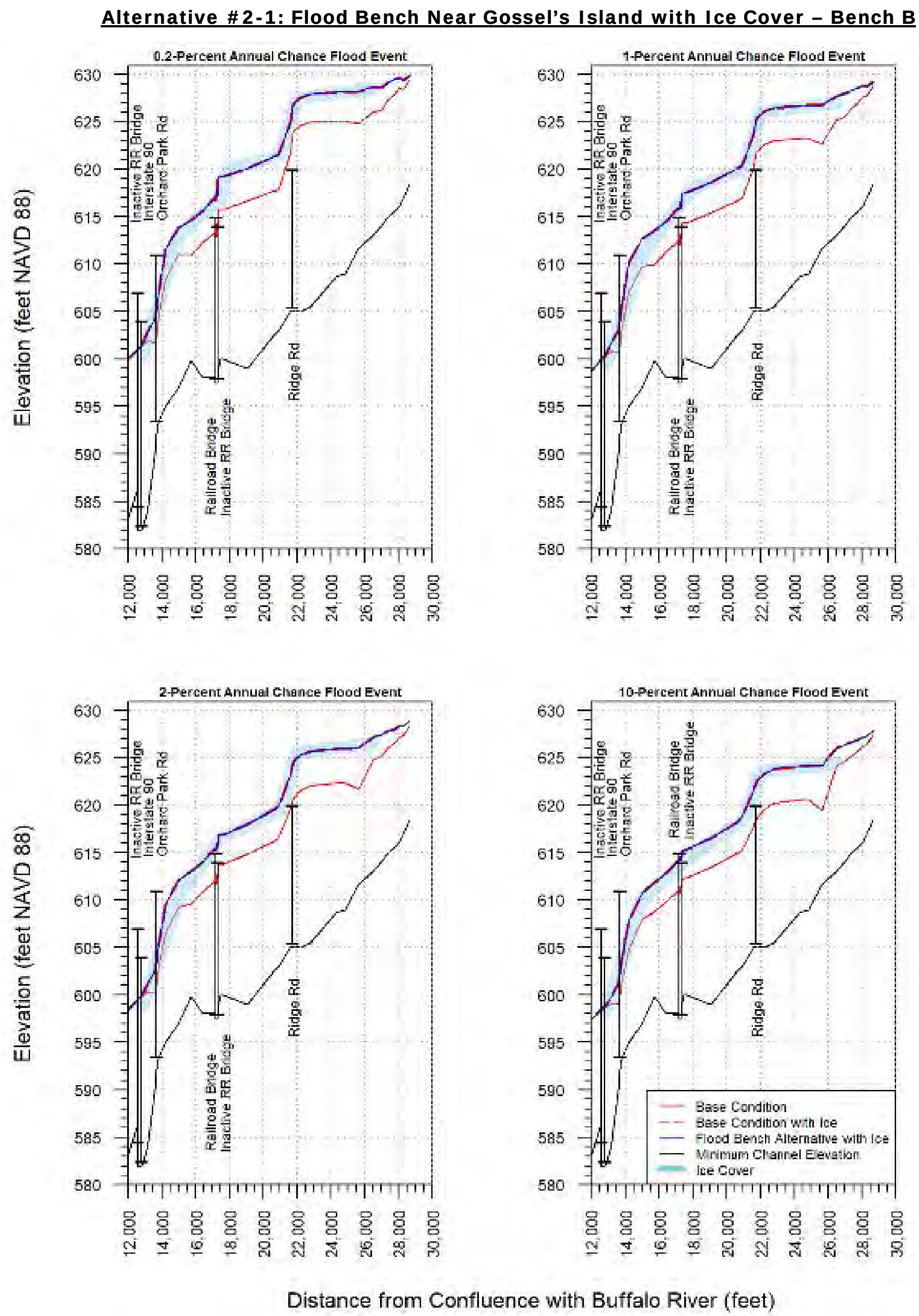

Figure 7-14. HEC-RAS ice-cover model simulation output results for Alternative #2-1 Bench B.

Alternative #2-1: Flood Bench Near Gossel's Island with Ice Cover – Bench C

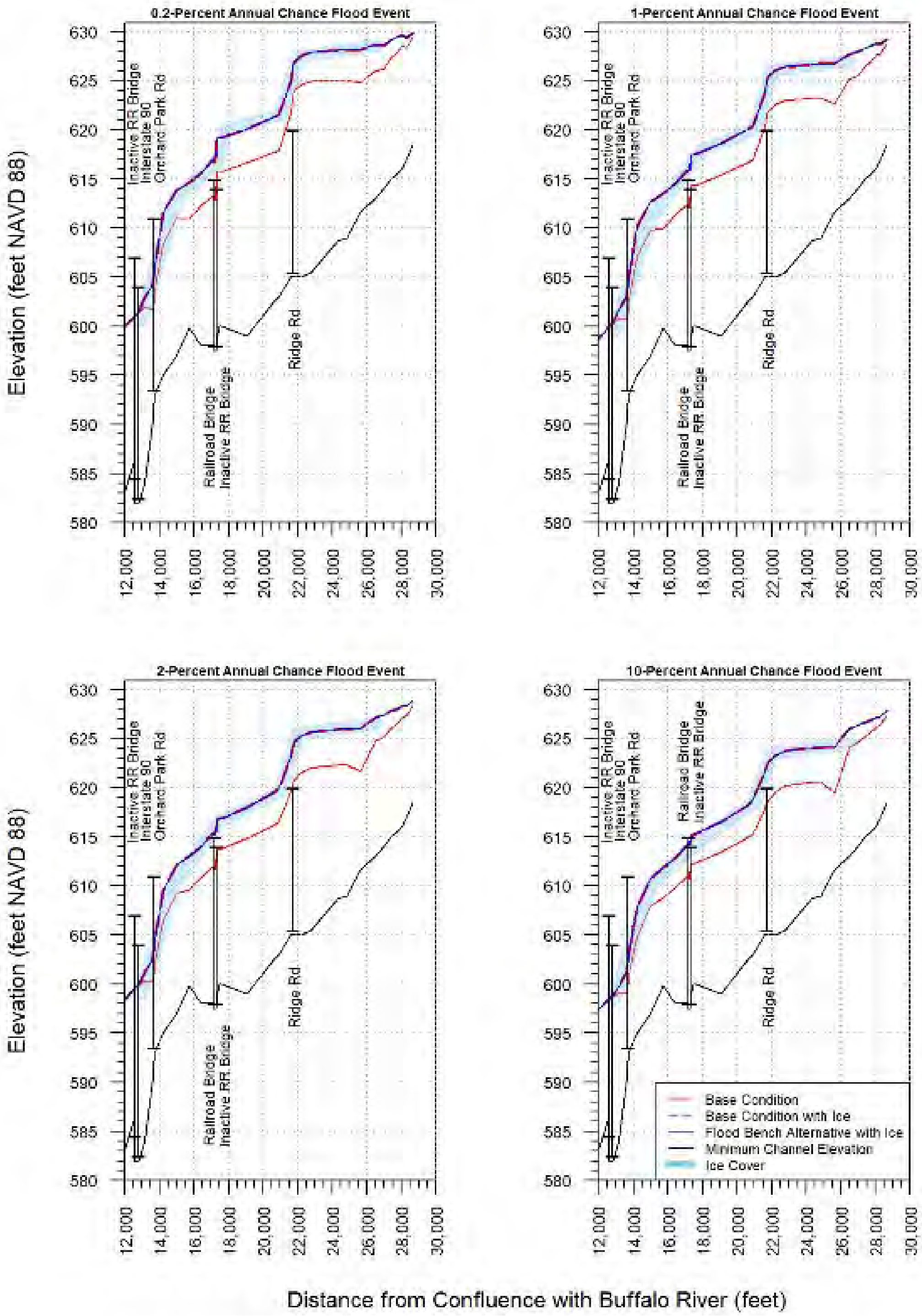

Figure 7-15. HEC-RAS ice-cover model simulation output results for Alternative #2-1 Bench C.

7.2.2 Alternative #2-2: Ice Piers and Flood Bench Near Gossel's Island

This measure is intended to address issues within High Risk Area #2 by providing additional flood storage and eliminating ice shoal formation at Gossel's Island, while also preventing ice migration downstream. This alternative would be located between river stations 230+00 and 260+00 and include the full flood bench described in Alternative 2-1 with the addition of 5-ft diameter ice piers located at river station 232+00, spaced 12-ft apart, similar to the ice control structure upstream located near Mill Road. The ice piers will stop break-up ice jams and create controlled jamming, forcing ice onto the associated flood bench. Ice piers in this location should reduce the contribution of upstream ice flow to any ice jams formed downstream near the confluence as a result of jamming along Buffalo Creek. In accordance with Alternative 2-1, this alternative could include a smaller flood bench. Analysis was performed based on the largest, fully built flood bench from Alternative 2-1.

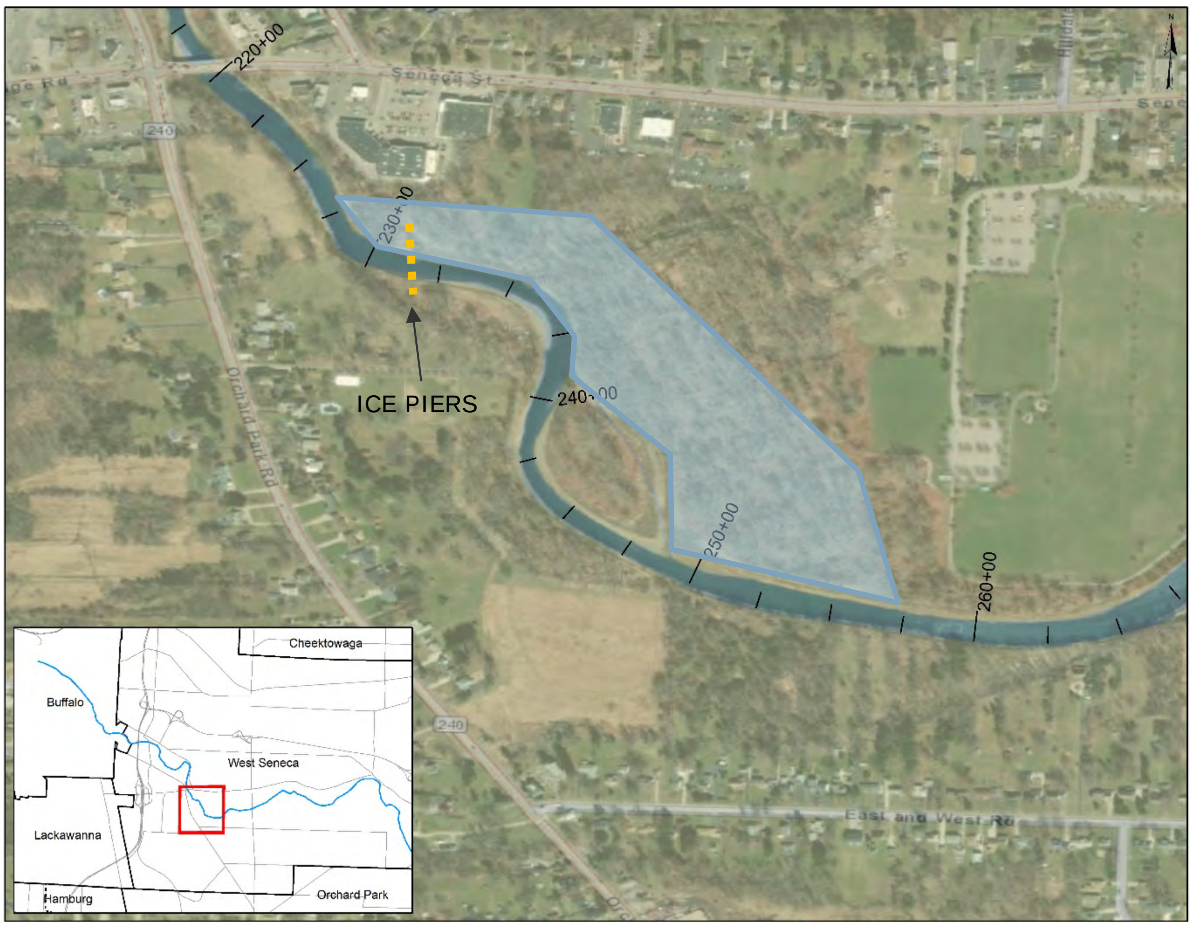

Figure 7-16. Location map for Alternative #2-2: Ice Piers and Flood Bench Near Gossel's Island.

Alternative #2-2: Ice Piers and Flood Bench Near Gossel's Island

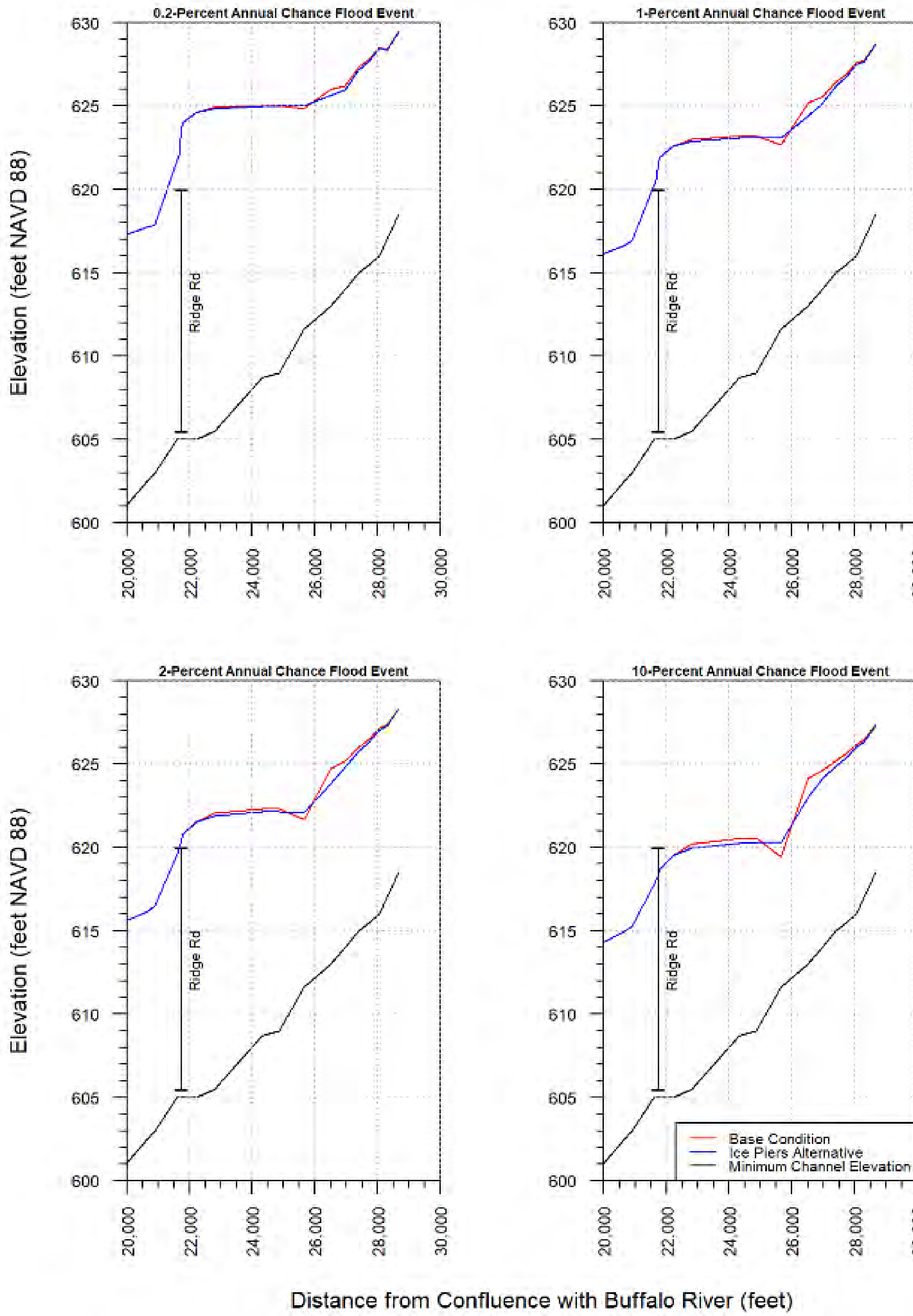

Figure 7-17. HEC-RAS model simulation output results for Alternative #2-2.

Due to the complex nature of the interaction of ice flow and ice piers, no ice simulations were performed to address the performance of the piers. The proposed condition modeling was performed to confirm that the addition of ice piers in the channel do not cause any adverse impacts on water surface elevation. The combination of ice piers and a 31-acre flood bench result in a water surface elevation reduction of 0.15-ft for the 2% annual chance flood event, while water surface elevations remain unchanged for, 0.2, 1 and 10% annual chance events.

This alternative provides a benefit of reducing ice jam formations downstream in more densely populated areas of Cazenovia Creek, which can potentially reduce flood risk and damages in these downstream areas.

Ice control structures require careful consideration due to the fact that certain conditions have to be in place for them to be effective. Additional hydrologic, hydraulic, and ice modeling simulations need to be performed to determine the effective distance of the damage area, and provide a place to trap the ice (gorge location) and allow floodwater to pass by without causing further damage (undeveloped floodplain). Flowage easements have to be secured upstream to mitigate increases in water surface elevations due to trapped ice. In addition, ice control structures can trap a sizeable amount of debris, requiring a high level of annual maintenance.

The Rough Order of Magnitude cost for this alternative is $9.6 million, including the full-sized bench from Alternative 2-1.

7.2.3 Alternative #2-3: Increase Ridge Road Bridge Opening

This measure is intended to address issues within High Risk Area #2 by providing a 4-ft vertical increase in the Ridge Road bridge opening located at river station 216+92. Sight distance was not analyzed at this stage of conceptual project planning; line of sight analysis will need to be considered if this alternative is advanced further in the design process. The Ridge Road bridge does not need to be widened since the bridge length is greater than the bankfull width of Cazenovia Creek.

The Ridge Road bridge does not meet NYDOT or CRRA draft guidelines for freeboard. According to the FEMA FIS profiles, the Ridge Road bridge is unable to pass the 1% annual chance flood. The base condition HEC-RAS model simulated the bridge only being able to pass the 10-percent annual chance flood with the low chord elevation roughly 0.2-ft below the 2% annual chance flood event water surface elevation. The bridge does not meet the NYSDOT recommended freeboard of 2-ft over the 2% annual chance flood hazard or the draft CRRA recommended 2-ft of freeboard over the 1% annual chance flood hazard. By upsizing the bridge opening, the cross-sectional flow area of the bridge opening can be increased allowing more water to flow through the bridge and potentially reducing backwater and flooding upstream.

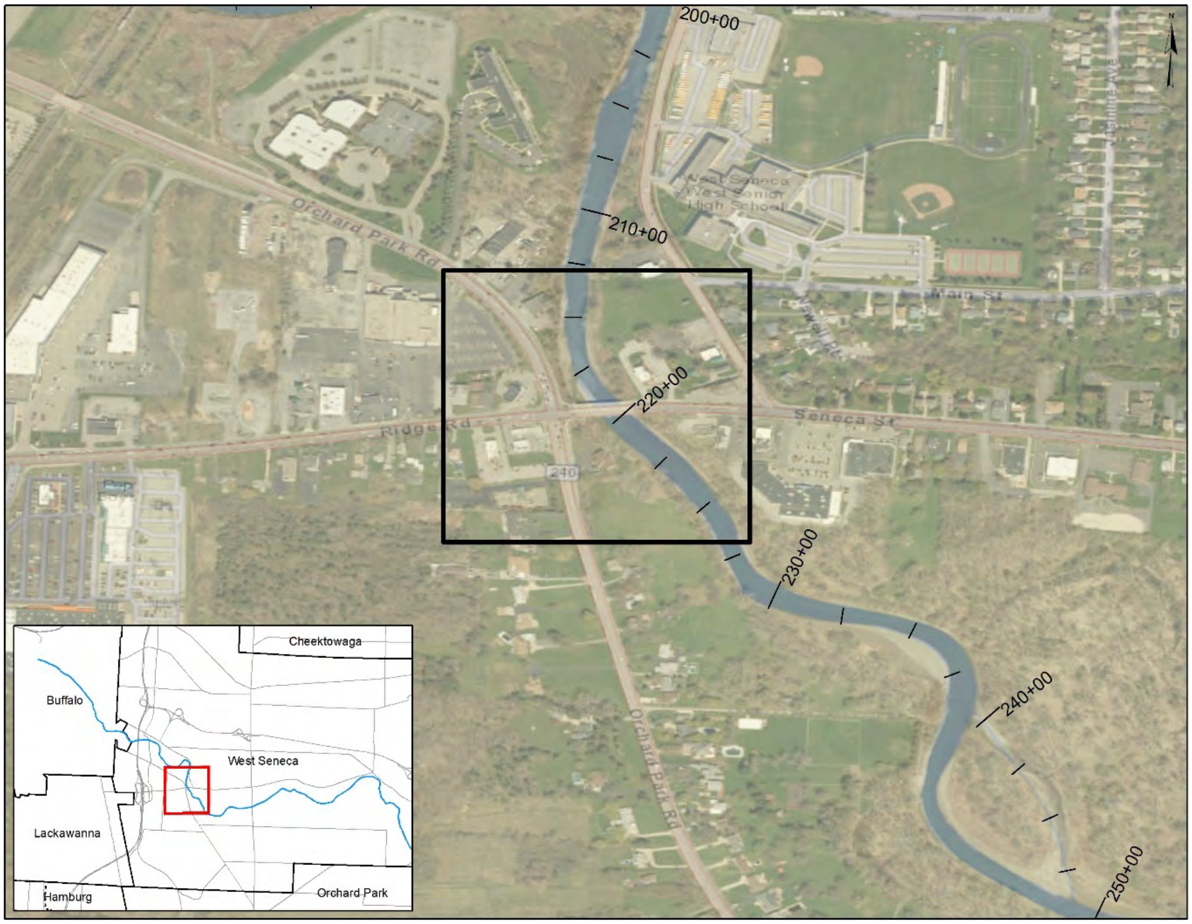

Figure 7-18. Location map for Alternative #2-3: Increase Ridge Road Bridge Opening.

The proposed condition modeling confirmed that increasing the height of the Ridge Road bridge will offer a flood reduction benefit in both open water, and ice jam conditions.

Alternative #2-3: Increase Ridge Road Bridge Opening

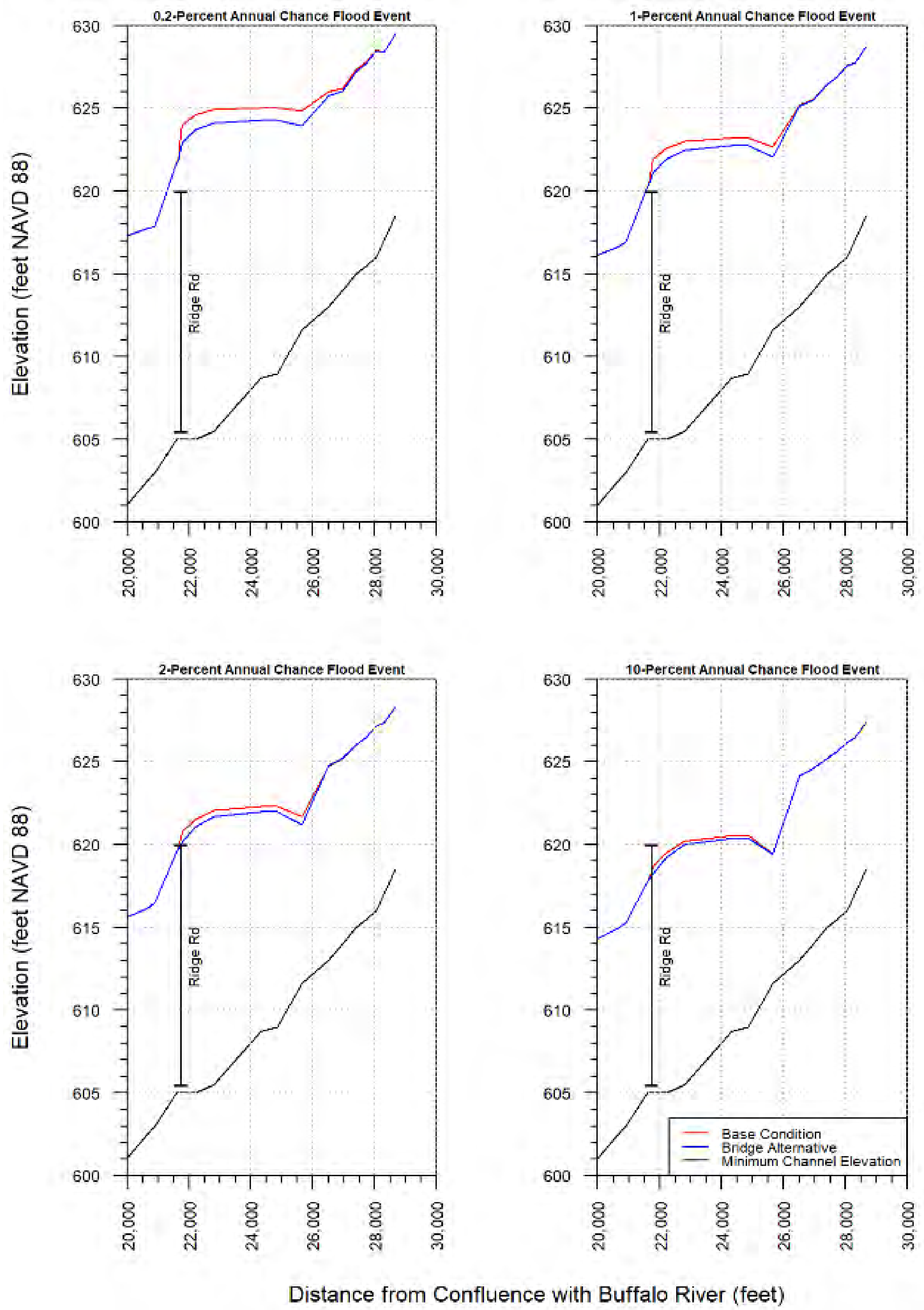

Figure 7-19. HEC-RAS model simulation output results for Alternative #2-3.

To assess the influence of ice jams on the Ridge Road bridge, an ice-cover simulation was performed with a 1-ft thickness ice cover. This simulation was intended to mimic the effects of a mild winter ice jam, which would reduce the cross-sectional area of the flow, and increase the in-channel roughness. In the presence of ice, the proposed condition modeling shows an approximately 0.37-ft reduction in water surface elevation due to the 4-ft height increase of the bridge while maintaining flow within the channel.

The potential water surface elevation reduction benefits of this alternative, for open water conditions, would extend upstream to the east side of the West Seneca Soccer Complex.

The Rough Order of Magnitude cost for this alternative is $7.8 million.

Alternative #2-3: Increase Ridge Road Bridge Opening with Ice Cover

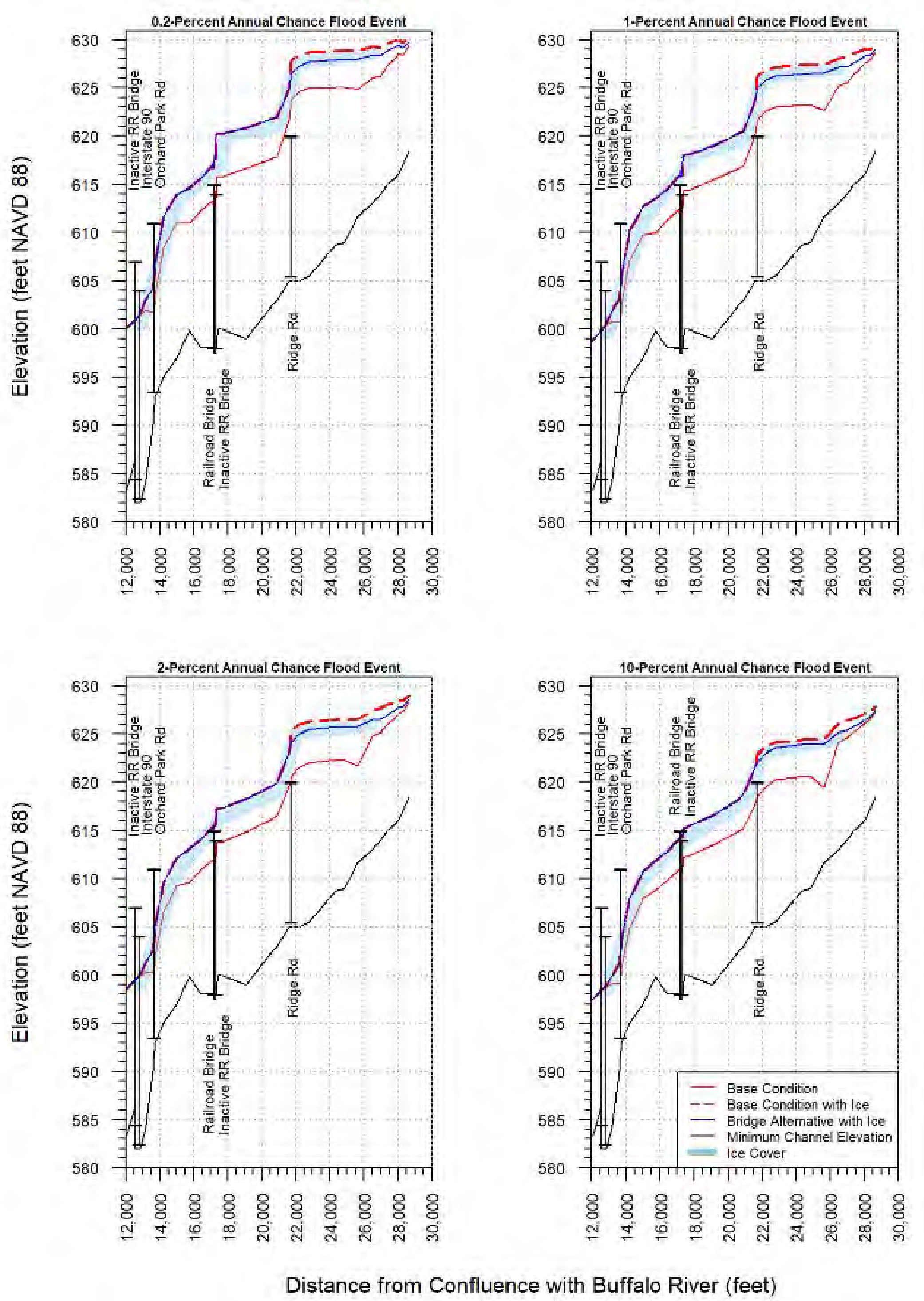

Figure 7-20. HEC-RAS ice-cover model simulation output results for Alternative #2-3.

7.3 HIGH RISK AREA #3

7.3.1 Alternative #3-1: Flood Bench Near River Station 150+00

This measure is intended to address issues within High Risk Area #3 by providing additional flood storage and cross-sectional area of flow. This strategy would require the excavation of approximately 7.15 acres of land along the left bank of the creek from river station 147+50 to 160+00. The flood bench is partially within the FEMA designated Special Flood Hazard Area (SFHA) or Zone AE, which are areas subject to inundation by the 1% annual chance flood event determined by detailed methods where Base Flood Elevations (BFEs) are shown.

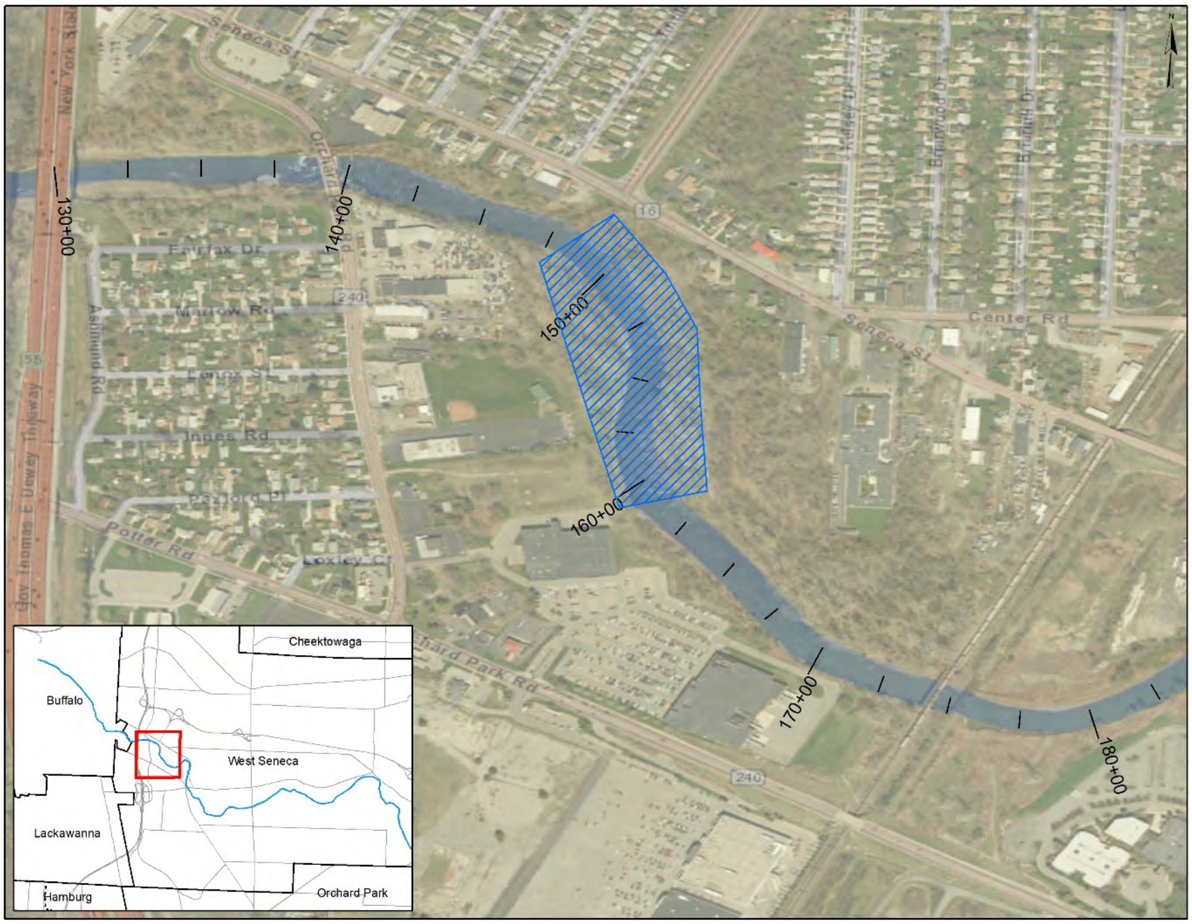

Figure 7-21. Location map for Alternative #3-1: Flood Bench Near River Station 150+00.

The proposed condition modeling confirmed that the creation of a flood bench will reduce the 1% annual chance flood event water surface elevation by approximately 0.84-ft.

To assess the influence of ice jams, an ice cover simulation was performed with a 1-ft thickness ice cover. This simulation was intended to mimic the effects of a mild winter ice jam, which would reduce the cross-sectional area of the flow, and increase the in-channel roughness. In the presence of ice, the proposed condition modeling shows an approximately 1.27-ft reduction of water surface elevation for the 10-year flood event.

The area downstream of the railroad bridges benefitted most from this flood bench alternative. This area is mainly commercial with numerous retail and essential businesses adjacent to Cazenovia Creek. Reducing flood risk downstream of the railroad bridges would benefit the numerous businesses in this area, and in turn, local residents who rely on these businesses.

The alternative simulations performed for the flood bench did not take into account the effects of the residual levee constructed during the Advanced Measures Project in response to the Blizzard of 1977 in Western New York on the flood bench. The levee is located on the left bank upstream of Orchard Park Road (NY-240). Prior to moving this alternative forward, additional modeling and design considerations would need to be employed to account for the effects of the residual levee.

The Rough Order of Magnitude cost for this alternative is $2.6 million.

Alternative #3-1: Flood Bench Near River Station 150+00

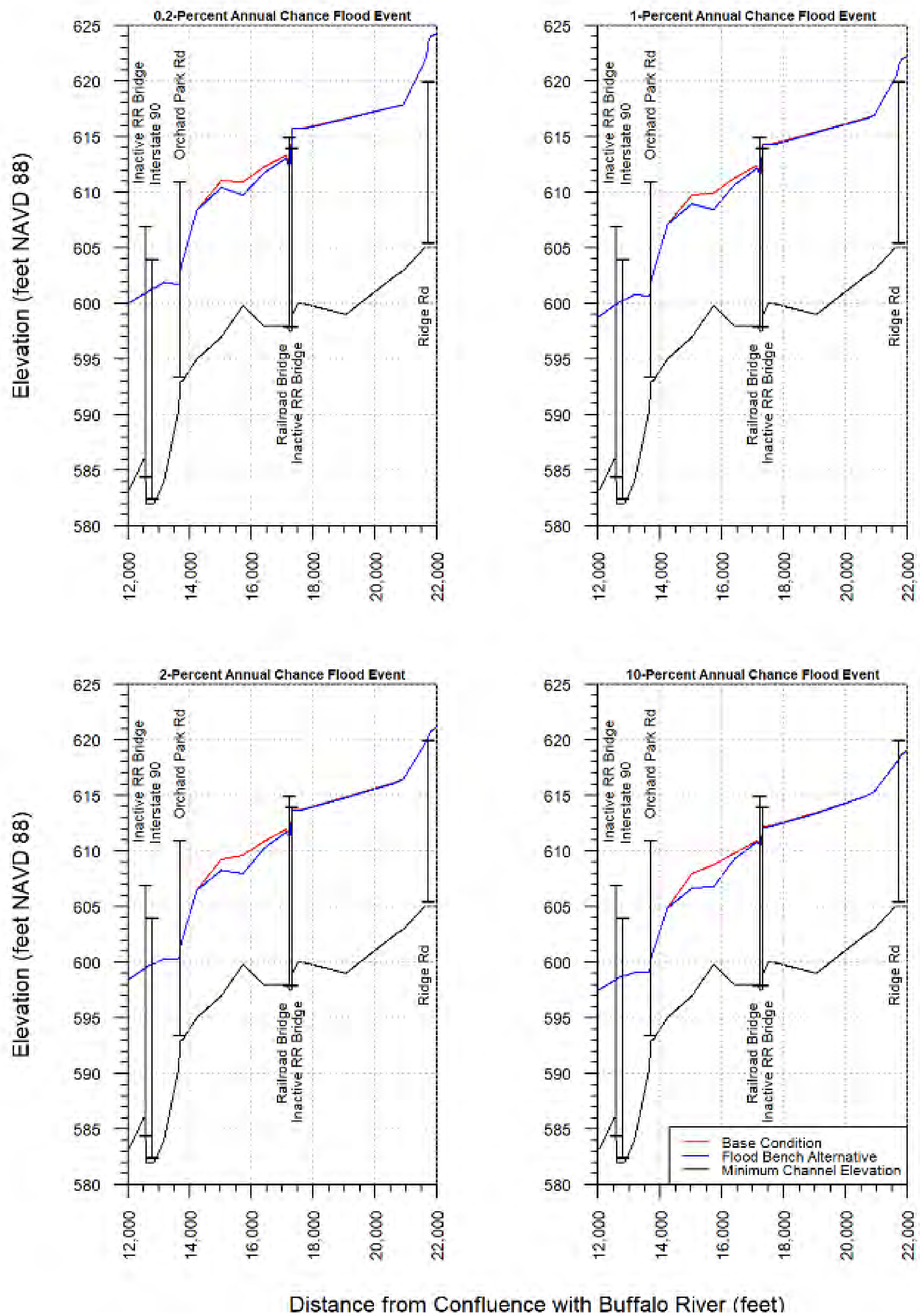

Figure 7-22. HEC-RAS model simulation output results for Alternative #3-1.

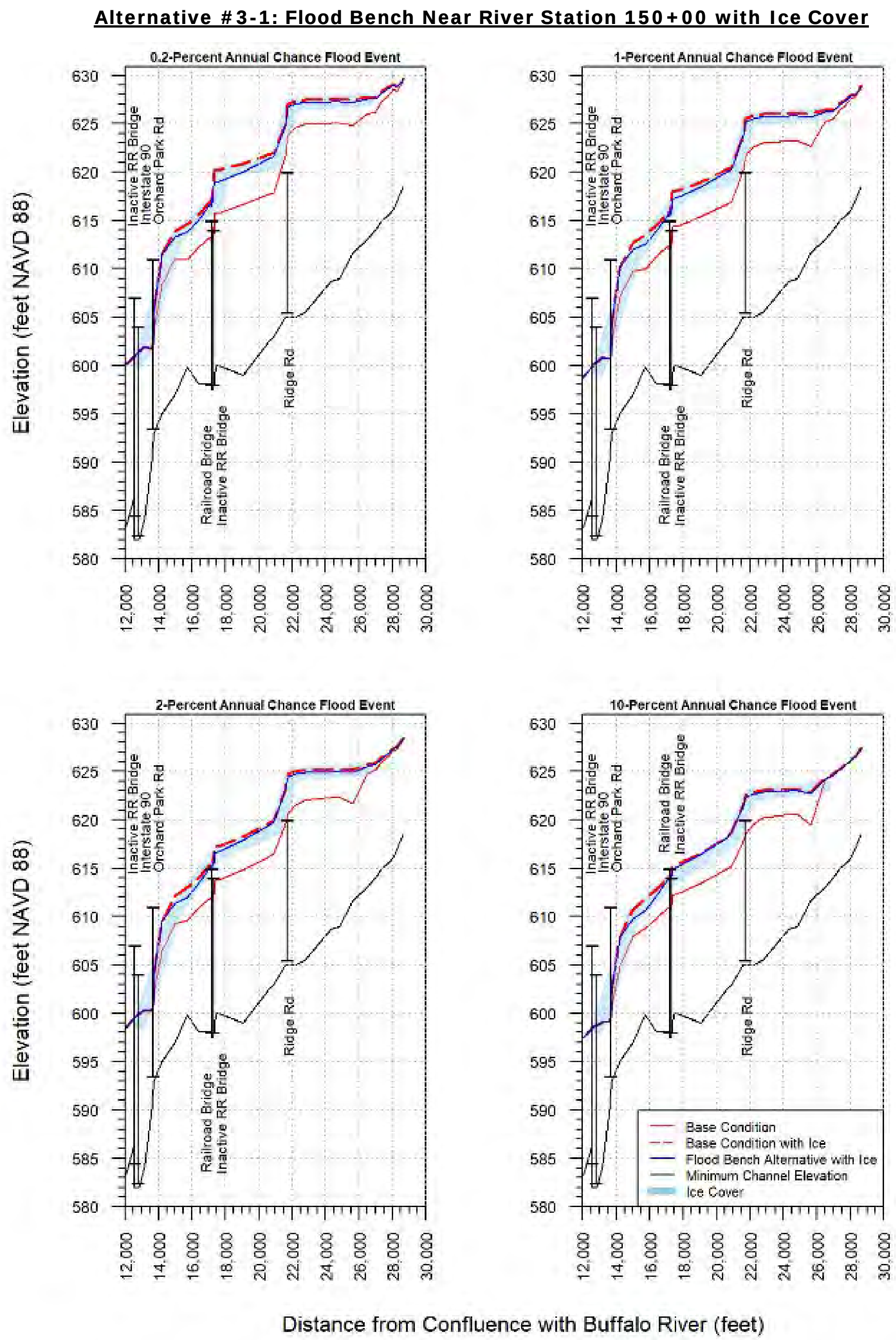

Figure 7-23. HEC-RAS ice-cover model simulation output results for Alternative #3-1.

7.3.2 Alternative #3-2: Flood Bench at River Station 190+00

This measure is intended to address issues within High Risk Area #3 by providing additional flood storage and cross-sectional area of flow. This strategy would require the potential excavation of approximately 12.5 acres of land along the left bank of Cazenovia Creek in the Town of West Seneca from river station 182+50 and 205+00.

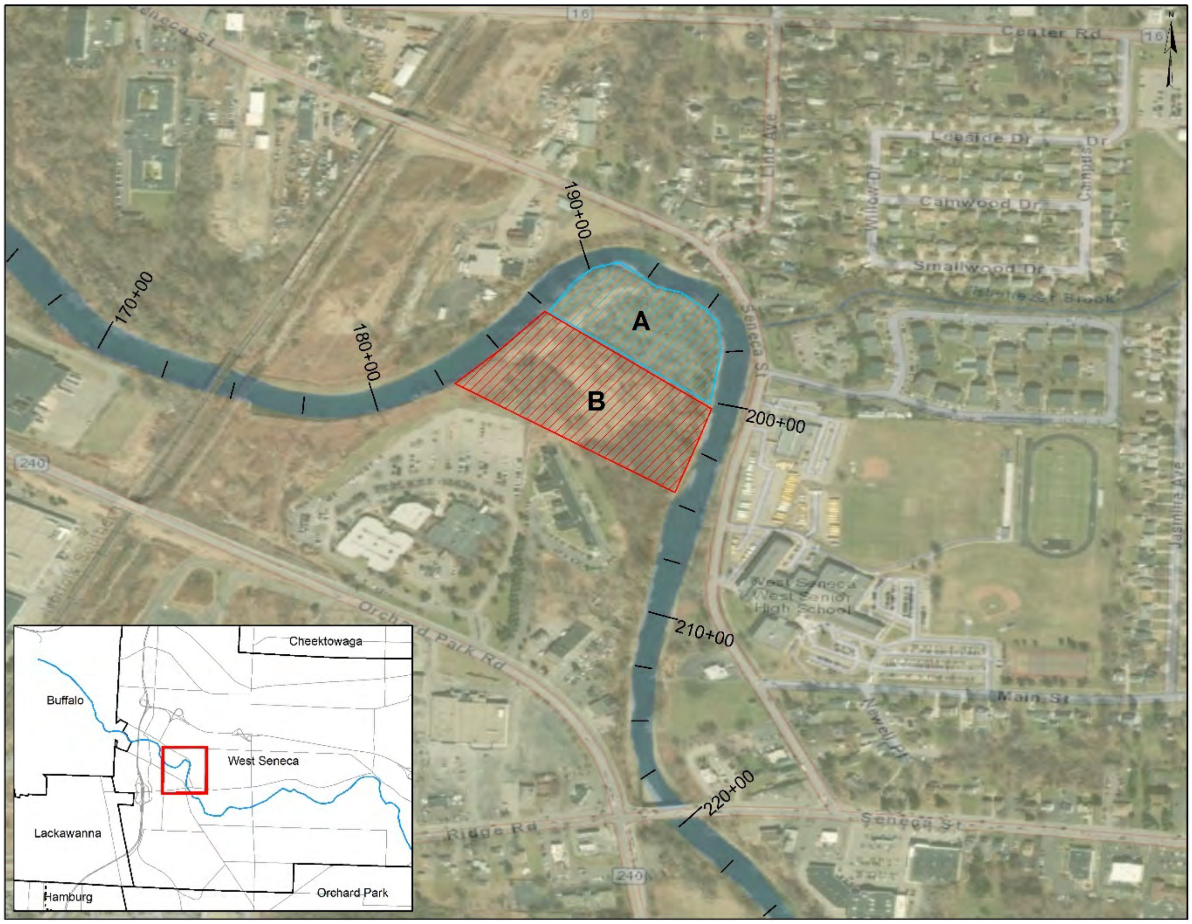

Figure 7-24. Location map for Alternative #3-2: Flood Bench at River Station 190+00.

The proposed condition modeling confirmed that the creation of a flood bench will reduce the 1% annual chance flood event water surface elevation by approximately 0.32-ft.

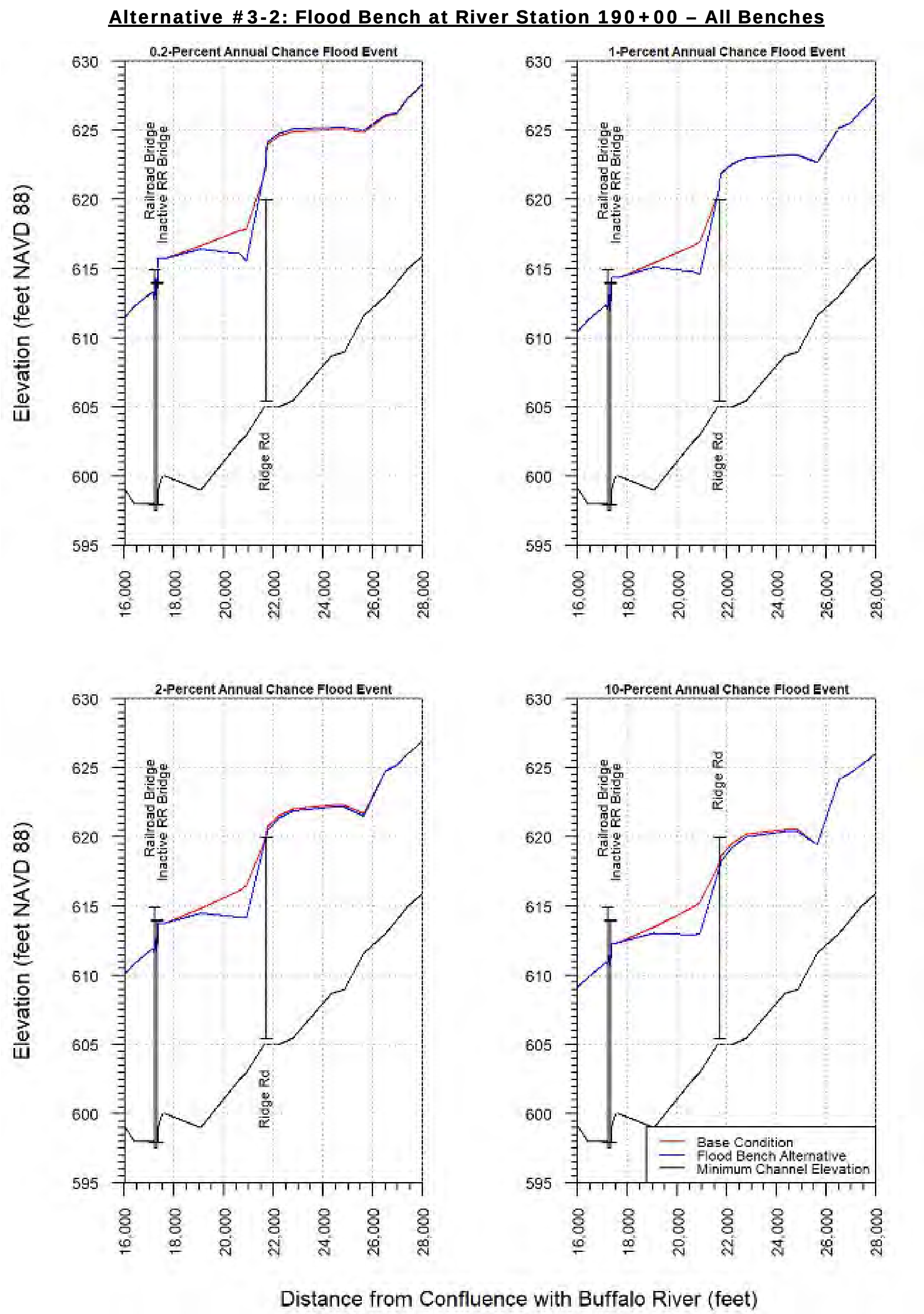

Figure 7-25. HEC-RAS model simulation output results for Alternative #3-2 All Benches.

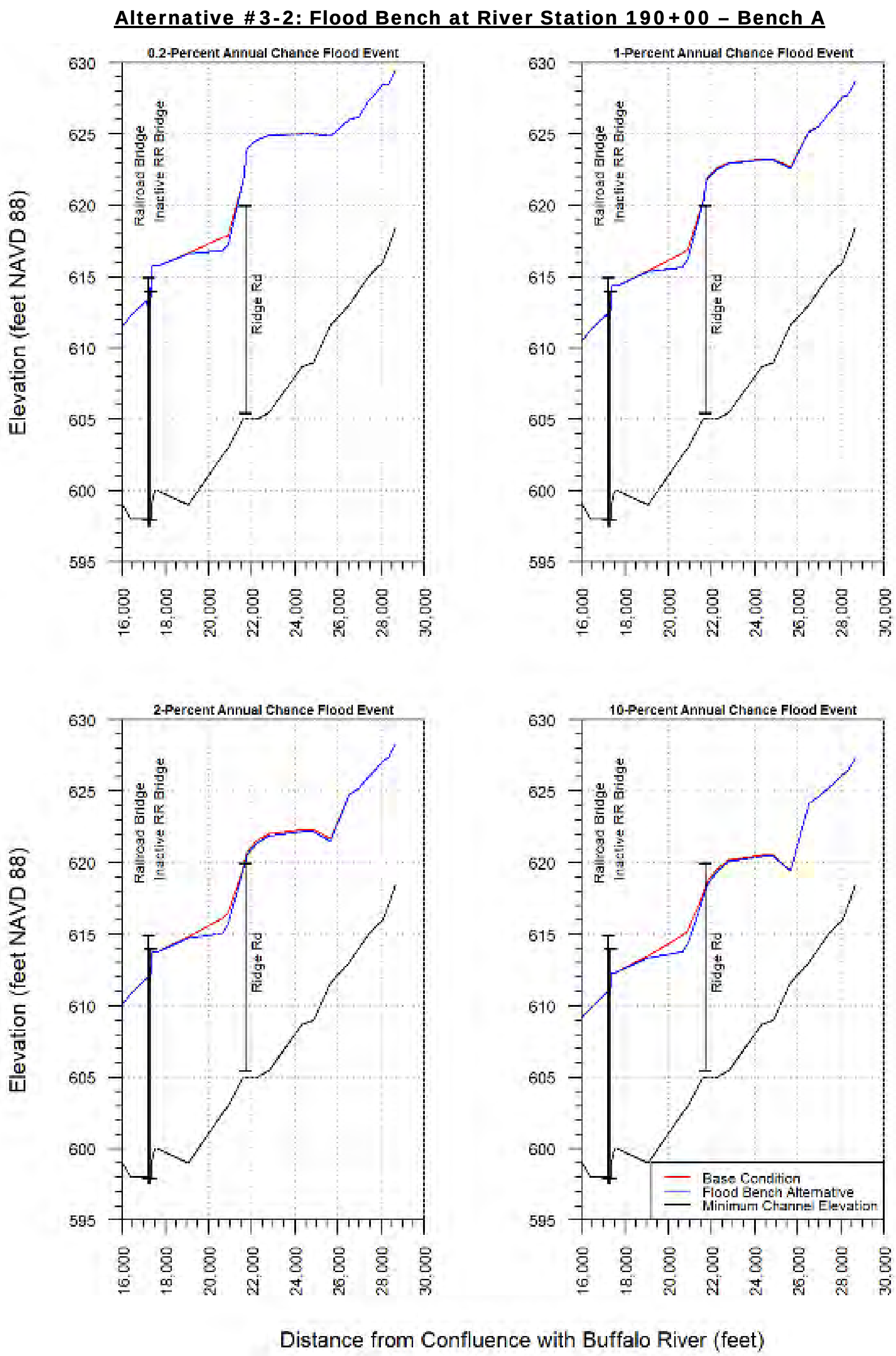

Figure 7-26. HEC-RAS model simulation output results for Alternative #3-2 Bench A.

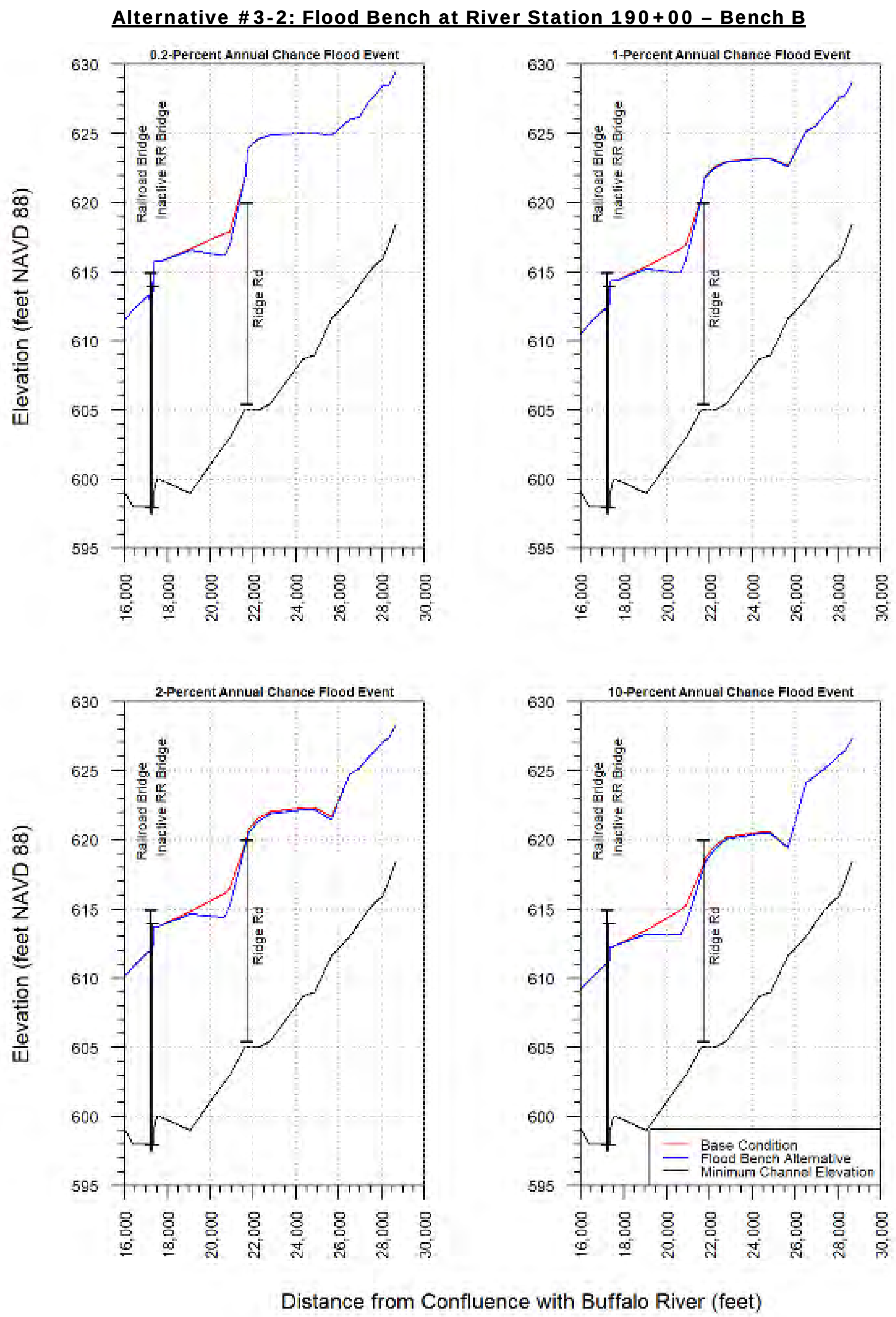

Figure 7-27. HEC-RAS model simulation output results for Alternative #3-2 Bench B.

To assess the influence of ice jams, an ice cover simulation was performed with a 1-ft thickness ice cover. This simulation was intended to mimic the effects of a mild winter ice jam, which would reduce the cross-sectional area of the flow, and increase the in-channel roughness. In the presence of ice, the proposed condition modeling shows an approximately 1.95-ft reduction of water surface elevation for the 10-year flood event.

The potential benefits of this alternative would be to reduce flood risk and damages to public and private infrastructure adjacent to the Cazenovia Creek between the railroad bridges and the Ridge Road bridge crossing for both open water and ice jam conditions. The West Seneca High School and residences along Seneca Street in this reach would benefit from the flood bench alternative by reducing water surface elevations of flood waters and potentially flood damages to infrastructure and property.

This alternative would require additional in-depth engineering and 2-D modeling to determine the impact that a flood bench would have on the hydrologic and hydraulic conditions of Cazenovia Creek in this reach. Installing a floodplain bench on the inside of a meander could potentially result in the creek carving a new channel through the newly created floodplain if the flood bench was improperly designed and/or constructed. This would result in an actual shortening of overall creek channel, which would likely increase flows and velocities through this area disrupting natural processes, including sediment and nutrient transport, aquatic habitats, fish migratory patterns, etc.

The Rough Order of Magnitude costs for this alternative are:

Bench A: $2.6 million

Bench B: $2.8 million

Total for both benches: $5.4 million

Alternative #3-2: Flood Bench at River Station 190+00 with Ice Cover – All Benches

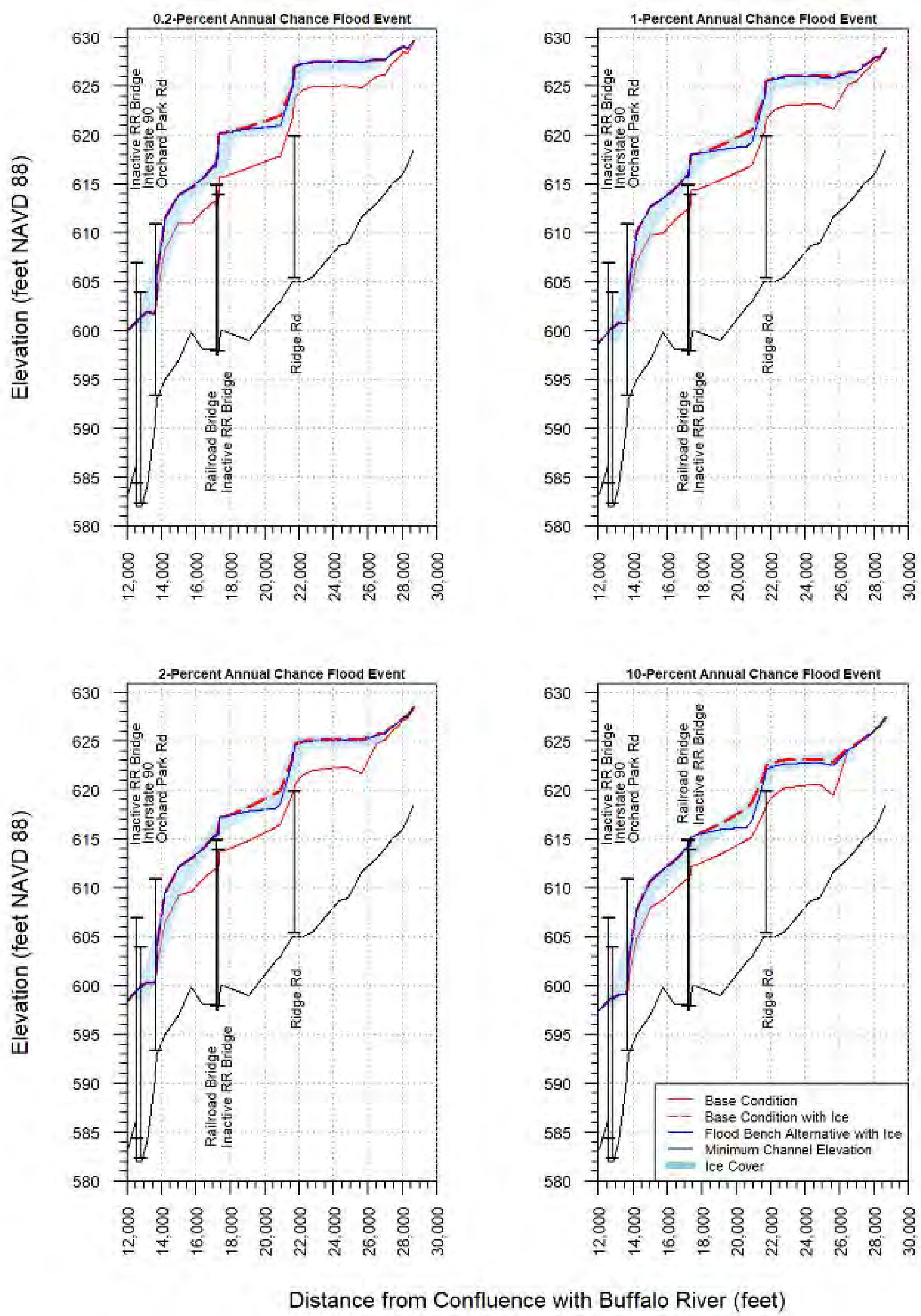

Figure 7-28. HEC-RAS ice-cover model simulation output results for Alternative #3-2 All Benches.

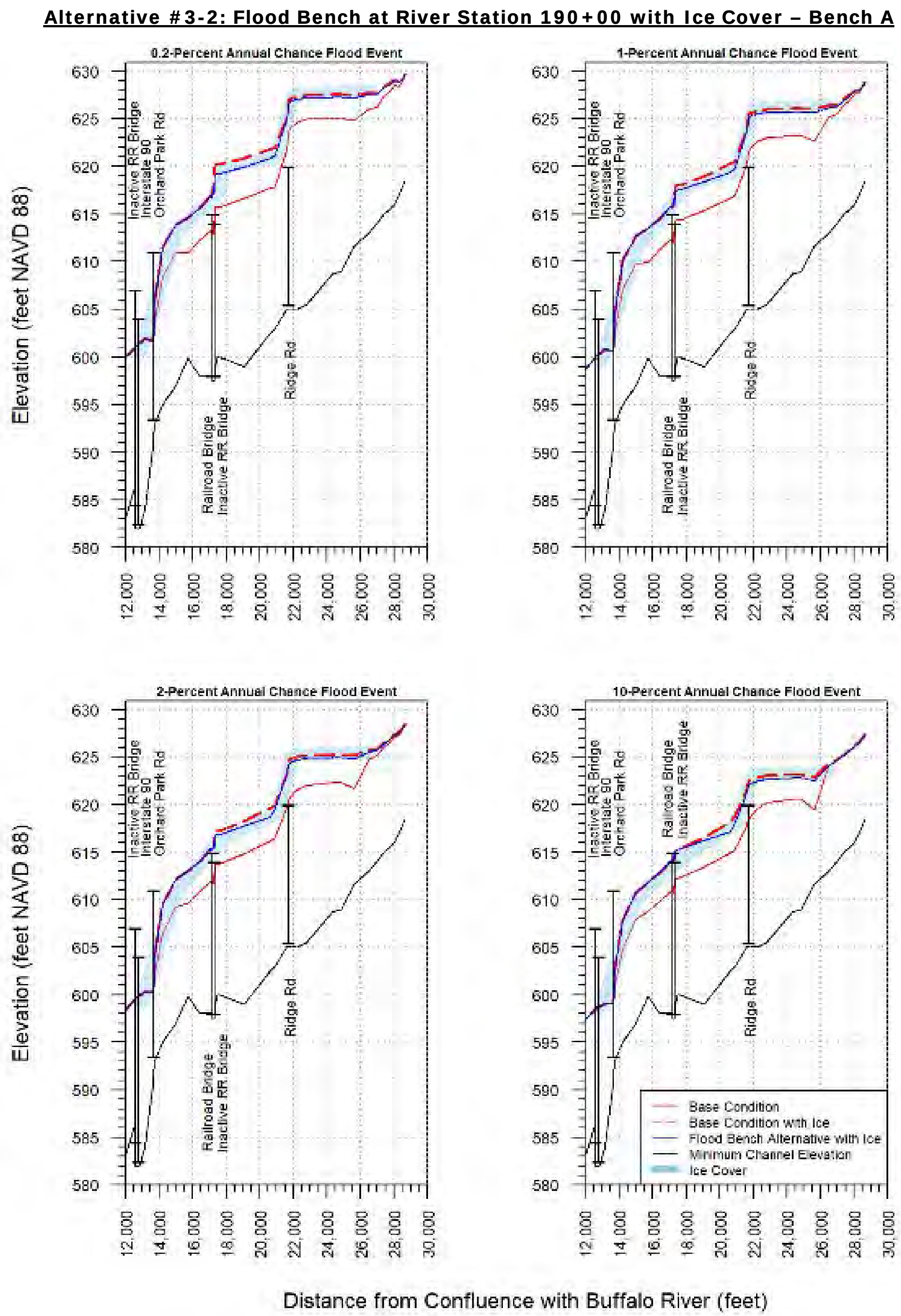

Figure 7-29. HEC-RAS ice-cover model simulation output results for Alternative #3-2 Bench A.

Alternative #3-2: Flood Bench at River Station 190+00 with Ice Cover –Bench B

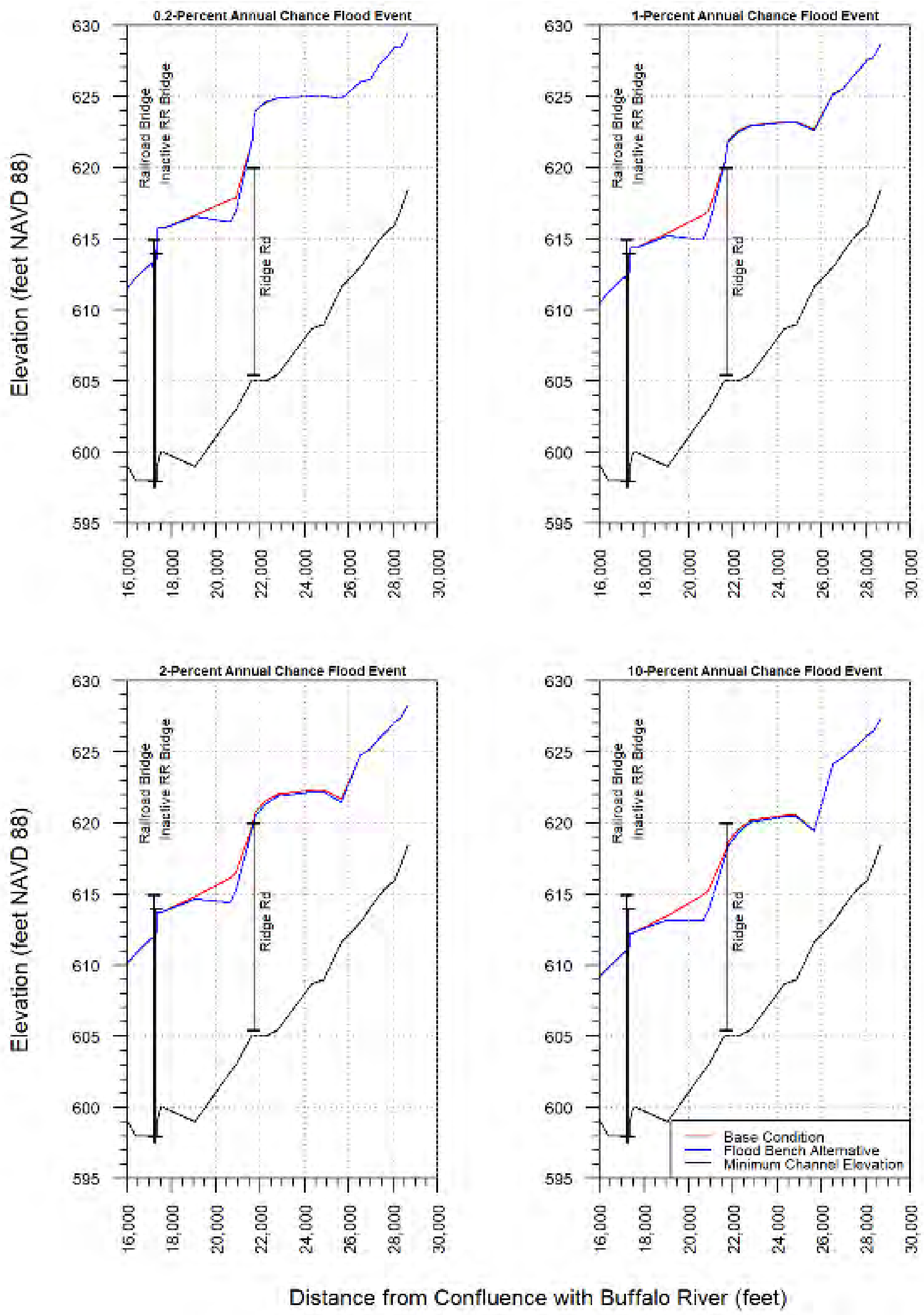

Figure 7-30. HEC-RAS ice-cover model simulation output results for Alternative #3-2 Bench B.

7.3.3 Alternative #3-3: Tree & Shrub Clearing Along River Station 190+00

Reducing large vegetation would provide additional floodplain width, reduce impediments to flow, and potentially reduce debris and sediment accumulation downstream in High Risk Area #3. The area where vegetation would be reduced would be the same location of the flood bench from the previous alternative along the left bank of Cazenovia Creek in the Town of West Seneca from river station 206+37 to 176+44. The total acreage of the clearing area would be 12.5 acres. This measure would potentially benefit and reduce the flood risk for the areas near the Western New York Medical Park and Edgewood Assisted Living at West Seneca, and offer additional storage for ice jamming during winter months, reducing ice flow downstream.

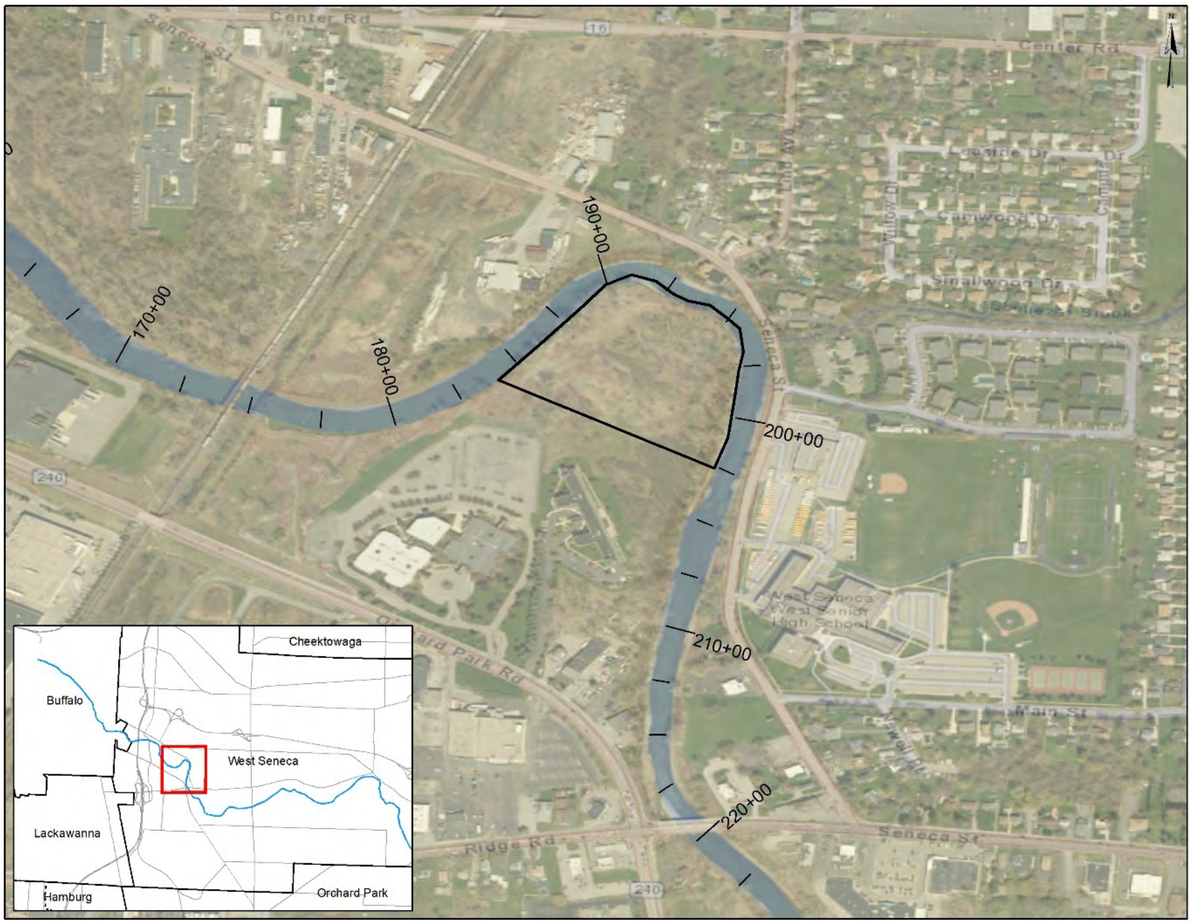

Figure 7-31. Location map for Alternative #3-3: Tree & Shrub Clearing Along River Station 190+00.

This scenario was simulated by reducing the Manning's n value coefficients in the overbank areas of Cazenovia Creek in the designated area. The proposed condition model results simulated water surface reductions of up to 1.45-ft in areas adjacent to and immediately upstream of the clearing area for a 500-year event. The potential benefits of this strategy are limited to the areas in the vicinity of and immediately upstream of the clearing area, specifically between the pair of railroad bridges and the Ridge Road bridge.

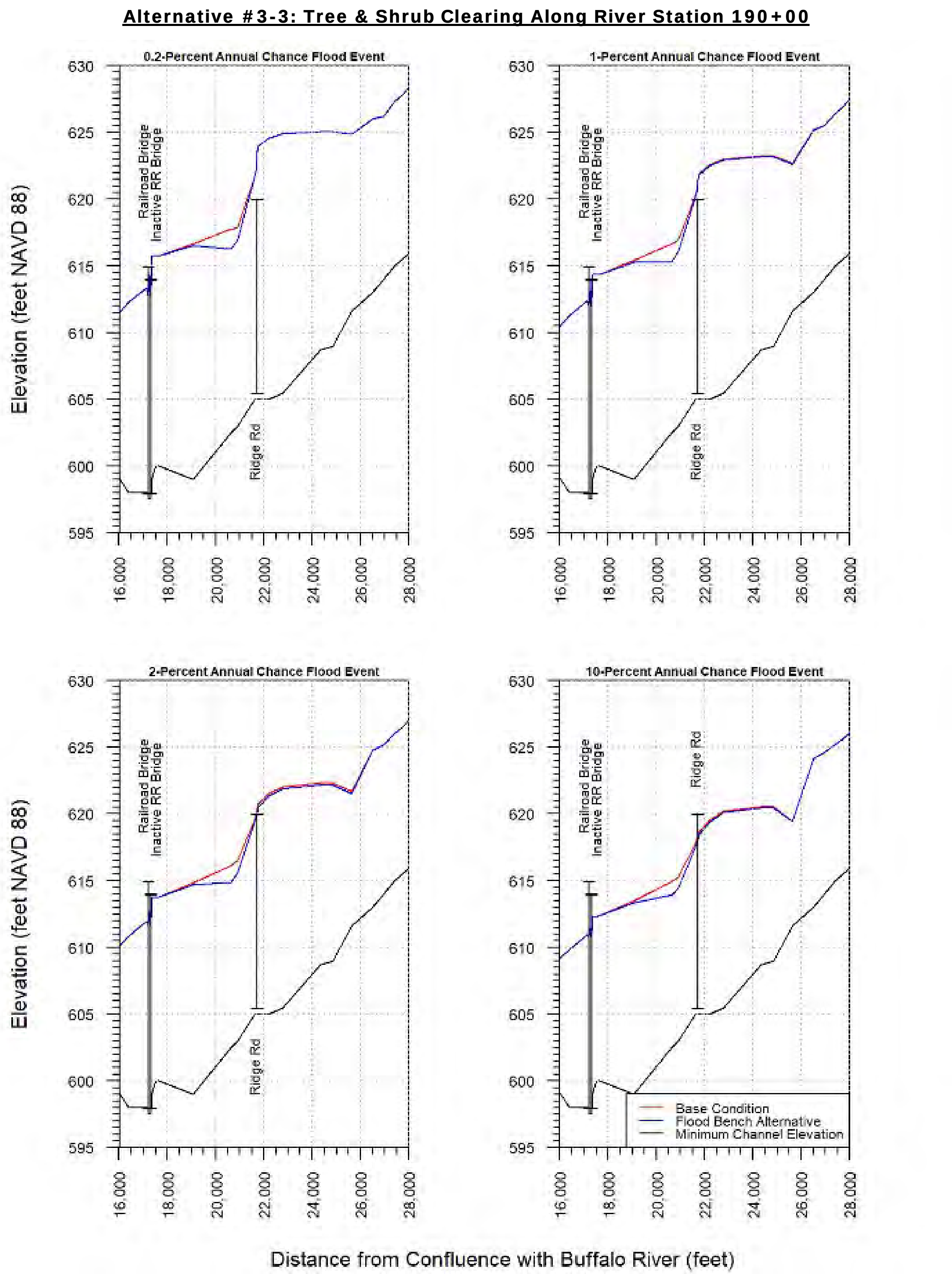

Figure 7-32. HEC-RAS model simulation output results for Alternative #3-3.

To assess the influence of ice jams, an ice cover simulation was performed with a 1-ft thickness ice cover. This simulation was intended to mimic the effects of a mild winter ice jam, which would reduce the cross-sectional area of the flow, and increase the in-channel roughness. In the presence of ice, the proposed condition modeling shows an approximately 0.69-ft reduction of water surface elevation for the 10-year flood event.

The potential benefits of this alternative would be to reduce flood risk and damages to public and private infrastructure adjacent to the Cazenovia Creek between the railroad bridges and the Ridge Road bridge crossing for both open water and ice jam conditions. The West Seneca High School and residences along Seneca Street in this reach would benefit from the flood bench alternative by reducing water surface elevations of flood waters and potentially flood damages to infrastructure and property.

This alternative presents numerous regulatory and environmental challenges, including applications, permitting, and restrictions that would need to be considered. In addition, environmental impact analyses should be performed to assess the potential effects the tree and shrub clearing would have on native species and habitats in the area. The NYSDEC should be consulted prior to pursuing this alternative to discuss all regulatory and environmental guidelines and restrictions.

The Rough Order Magnitude cost for this measure is $450,000, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

Alternative #3-3: Tree & Shrub Clearing Along River Station 190+00 with Ice Cover

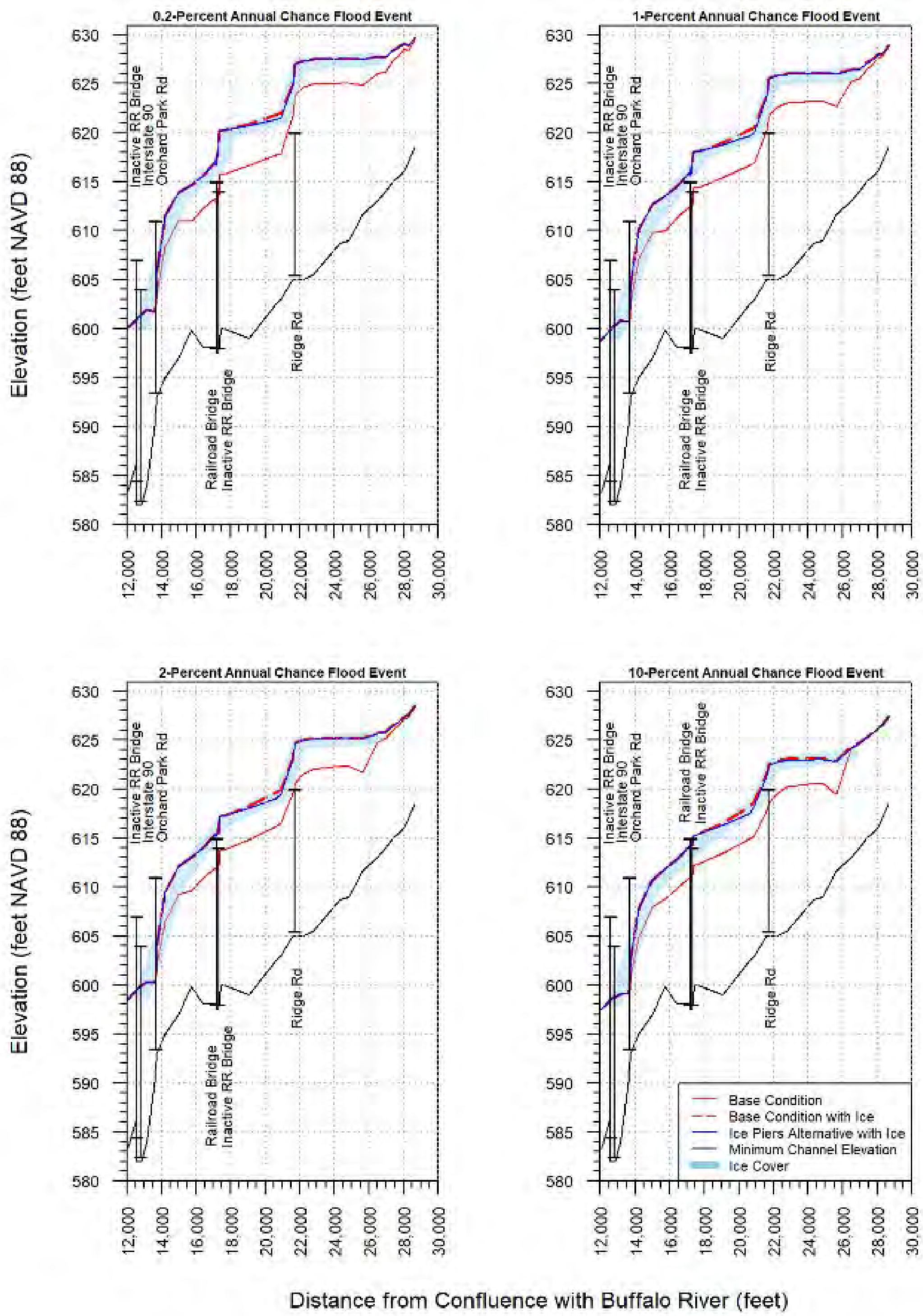

Figure 7-33. HEC-RAS ice-cover model simulation output results for Alternative #3-3.

7.4 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 2016c).

7.4.1 Alternative #4-1: Early Flood Warning 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 2016c).

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 prepare ice, and plan regarding resources needed for the upcoming ice jam and consequential flooding. And 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 2016c).

The Rough Order Magnitude cost for this strategy is approximately $120,000.

7.4.2 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 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 Cazenovia 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 debris should be removed and whether a permit will be required.

The Rough Order Magnitude cost for this strategy is approximately $20,000 annually (estimated six days for labor / equipment costs).

7.4.3 Alternative #4-3: Ice Management

This strategy is intended to control ice-jam formation by maintaining ice coverage in high-risk sections of Cazenovia 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 2016c).

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 operational costs for equipment.

7.4.4 Alternative #4-4: Flood Buyout 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 Cazenovia Creek watershed, there are approximately 3,900 residences within the FEMA 1 and 0.2% annual chance flood hazard zones. In addition, there are 7 FEMA Repetitive Loss (RL) and no Severe Repetitive Loss (SRL) properties located within the watershed. Figure 8-1 displays the tax parcels and repetitive loss properties within the City of Buffalo and Town of West Seneca along Cazenovia Creek (FEMA 2019d; NYSGPO 2019).

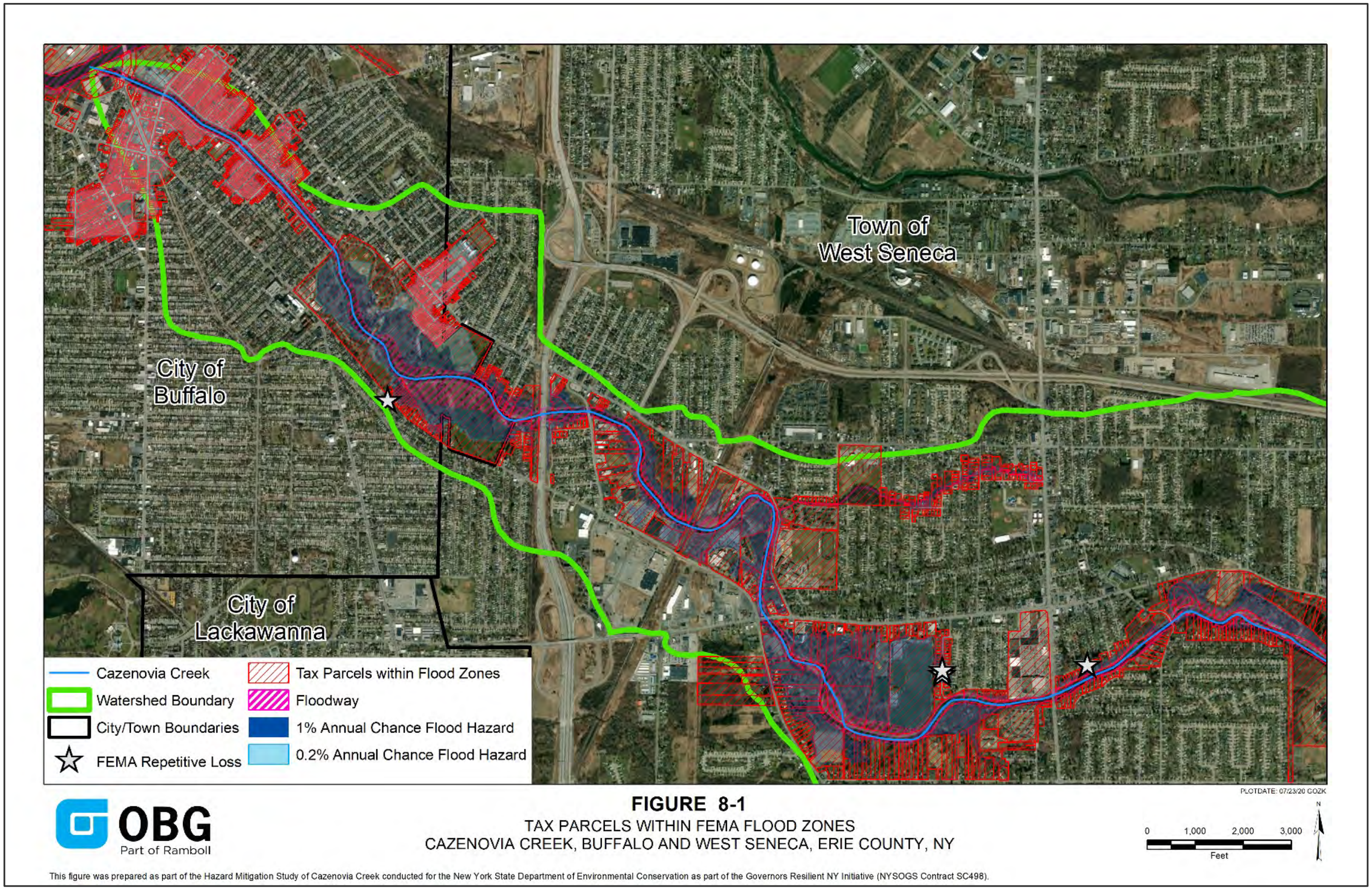

Figure 8-34. Tax parcels within FEMA flood zones, Cazenovia Creek, Buffalo and West Seneca, Erie County, NY.

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 to Cazenovia 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.

7.4.5 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 2015b).

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 involve 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. In addition, floodwalls or levees as a retrofit measure will not bring the building into compliance with NFIP requirements for Substantial Improvement / Damage (FEMA 2013).

- *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.

7.4.6 Alternative #4-6: Area Preservation / Floodplain Ordinances

This alternative proposes municipalities within the Cazenovia 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 Cazenovia Creek watershed.

8. 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.

8.1 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.

8.2 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.

8.3 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.

8.4 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

8.4.1 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.

8.4.2 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 CFAs in 2020 was postponed due to the financial uncertainties surrounding the COVID-19 outbreak.

8.4.2.1 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.

8.4.2.2 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.

8.4.3 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%), and performing any necessary operation and maintenance for a ten-year period. Through EWP, the NRCS may pay up to 75% of the construction costs of emergency measures, with up to 90% 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.

8.4.4 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.

8.4.4.1 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.

8.4.4.2 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. 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% of the eligible activity costs. FEMA may contribute up to 100% federal cost share for severe repetitive loss properties, and up to 90% 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

9. SUMMARY

The City of Buffalo and Town of West Seneca have had a history of flooding events along Cazenovia Creek. Flooding in the Towns 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 City of Buffalo and Town of West Seneca, and Erie County, are studying, addressing, and recommending potential flood mitigation projects for Cazenovia Creek as part of the Resilient NY Initiative.

This report analyzed the historical and present day causes of flooding in the Cazenovia 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 Cazenovia 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 Cazenovia Creek by combining the reduction potential of the mitigation measures being constructed.

Based on the flood mitigation analyses performed in this report, the largest factor for ice jams along Cazenovia Creek, specifically within the concrete lined channel section within the City of Buffalo, is the formation of ice jams along the Buffalo River. The mitigation measure that would provide the greatest reductions in ice formation along Cazenovia Creek would be the ice piers alternative. The most cost effective of these alternatives would be reducing the large vegetation area adjacent to Western New York Medical Park; however, there would be an overall greater effect in water surface elevations if multiple alternatives were built along Cazenovia 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 Stevenson Street and Warren Spahn Way bridge crossings benefited from increased bridge openings. 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 Cazenovia 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 Cazenovia 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 13 is a summary of the proposed flood-mitigation measures, including modeled water surface elevation reductions and estimated ROM costs.

Table 13. Summary of Flood Mitigation Measures

Alternative No.	Description	Max. Change in Water Surface Elevation (ft)	ROM cost ($U.S. dollars)
1-1	Increase Stevenson Street Bridge Opening	-1.1	$4.7M
1-2	Increase Warren Spahn Way Bridge Opening	-3.7	$5.9M
2-1	Flood Bench	-0.9	$9M
2-2	Ice Piers	-0.15	$9.6M
2-3	Increase Ridge Road bridge opening	-0.37	$7.8M
3-1	Flood Bench	-0.84	$2.6M
3-2	Flood Bench	-0.32	$5.3M
3-3	Remove large vegetation	-1.45	$450k
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 Program	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)

10. CONCLUSION

Municipalities affected by flooding along Cazenovia 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 Cazenovia 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 Cazenovia 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 # SC805**
Cazenovia Creek – Erie County, New York			**20-May-2020**
Year	**Data Type**	**Document Title**	**Author**
1966	Report	Flood Plain Information – Cazenovia Creek, NY	United States Army Corps of Engineers (USACE)
1971	Report	Flood Plain Information – Cazenovia Creek, NY	United States Army Corps of Engineers (USACE)
1977	Report	Interim Report on Feasibility of Flood Management in Cazenovia Creek Watershed	United States Army Corps of Engineers (USACE)
1983	Report	Flood characteristics of urban watersheds in the United States	United States Geologic Service (USGS)
1986	Report	Detailed Project Report and Environmental Impact Statement – Cazenovia Creek – West Seneca, New York	United States Army Corps of Engineers (USACE)
1991	Report	Regionalization of Flood Discharges for Rural, Unregulated Streams in New York, Excluding Long Island	United States Geologic Service (USGS)
1992	Report	Flood Insurance Study (FIS), Erie County	Federal Emergency Management Agency (FEMA)
2000	Report	Cazenovia Creek Ice-Control Structure	Cold Regions Research and Engineering Laboratory (CRREL) - Lever, Gooch & Daly
2000	Report	Development of a Contour Map Showing Generalized Skew Coefficients of Annual Peak Discharges of 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)
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)
2015	Report	Erie County, New York Multi-Jurisdictional Hazard Mitigation Plan Update	URS Engineering (AECOM)
2016	Report	Cazenovia Creek Ice Control Structure to Get Upgrades	United States Army Corps of Engineers (USACE)
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)

Year	Data Type	Document Title	Author
2019	Report	Flood Insurance Study (FIS), Erie County	Federal Emergency Management Agency (FEMA)
2019	Report	Bridge Manual	New York State Department of Transportation (NYSDOT)
N.D.	Report	Cazenovia Creek Flood Damage Reduction Project	New York State Department of Environmental Conservation (NYSDEC)
2008	Data	Erie County, NY - LiDAR Terrain Elevation	New York State Department of Environmental Conservation (NYSDEC)
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	Ice Jam Database	Cold Regions Research and Engineering Laboratory (CRREL)
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	Storm Events Database	National Centers for Environmental Information (NCEI)
2019	Data	Tax Parcels, Parks, Public Schools, Sheriff Stations	New York State Office of Real Property Tax Services (NYSORPTS)
2019	Data	USGS 04215000 Cayuga Creek near Lancaster	United States Geologic Service (USGS)
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)

Year	Data Type	Document Title	Author
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)

APPENDIX B
FIELD DATA COLLECTION FORM EXAMPLES

Stream Channel Classification (Level II)

Wisconsin Job Sheet 811

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

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: ______________________

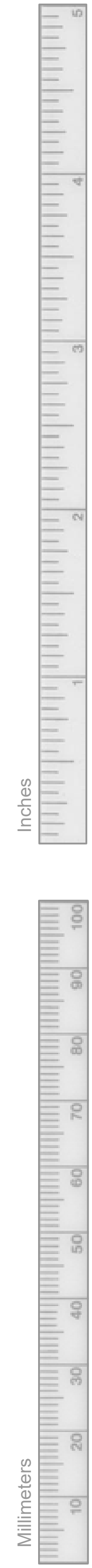
Horizontal Datum: NAD ________ Projection: ☐Transverse Mercator ☐Lambert Conformal Conical

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 #	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: _____________

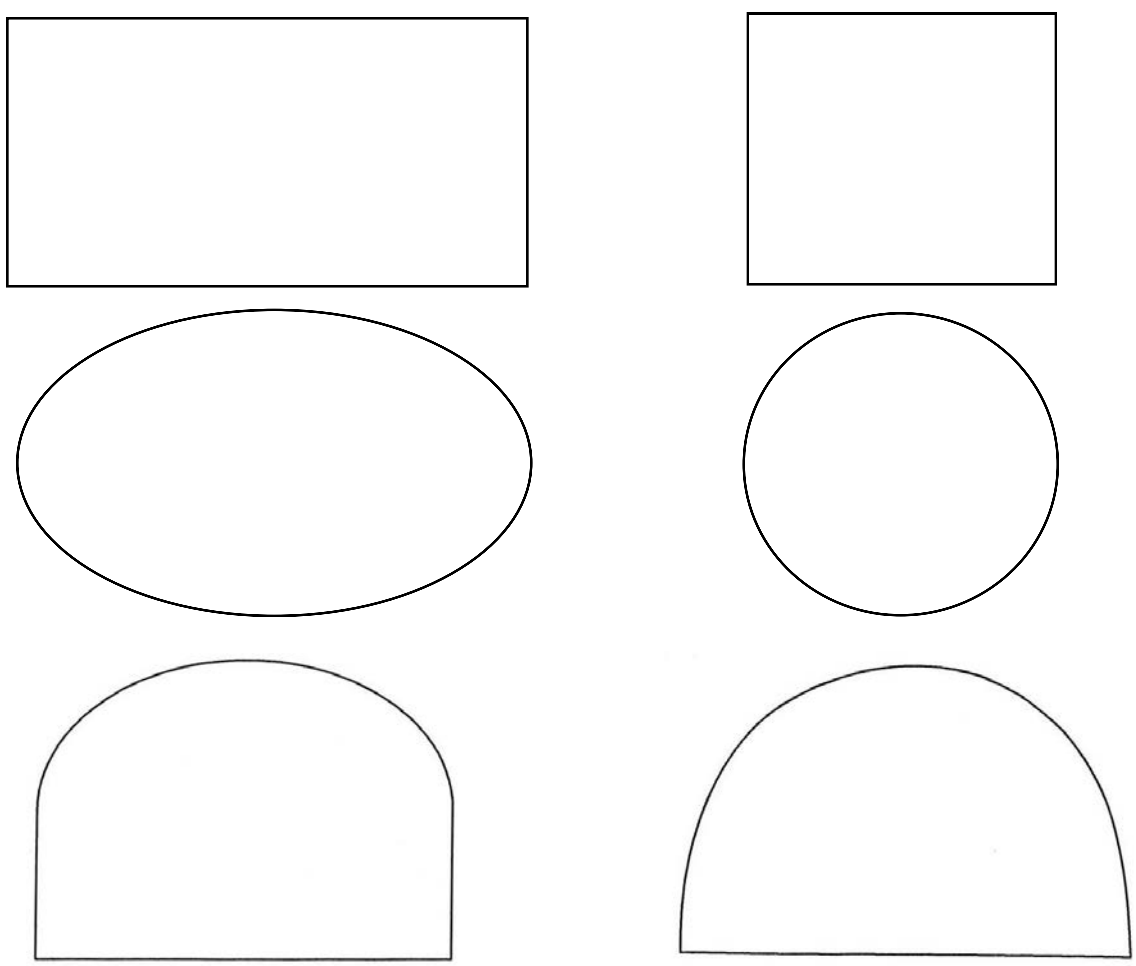
Description:

____

____

____

Typical Culvert Shapes (fill in dimensions)



APPENDIX C
PHOTO LOGS

APPENDIX C. PHOTO LOG	
Photo log of select locations along Cazenovia Creek.	
Photo No. 1 **Description:** Facing upstream from Stevenson Street bridge	
Photo No. 2 **Description:** Facing downstream from Cazenovia Street bridge	

Photo No. 3 **Description:** Cazenovia Street bridge	
Photo No. 4 **Description:** Warren Spahn Way bridge	

Photo No. 5 Description: Facing upstream towards Interstate 90 from Orchard Park Road bridge	
Photo No. 6 Description: Facing downstream from the West Seneca Soccer Complex	

Photo No. 7 **Description:** Facing downstream from Union Road bridge	
Photo No. 8 **Description:** Mill Road bridge	

Photo No. 9 **Description:** Facing upstream from Leydecker Road bridge	
Photo No. 10 **Description:** Facing upstream from Northup Road bridge	

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)

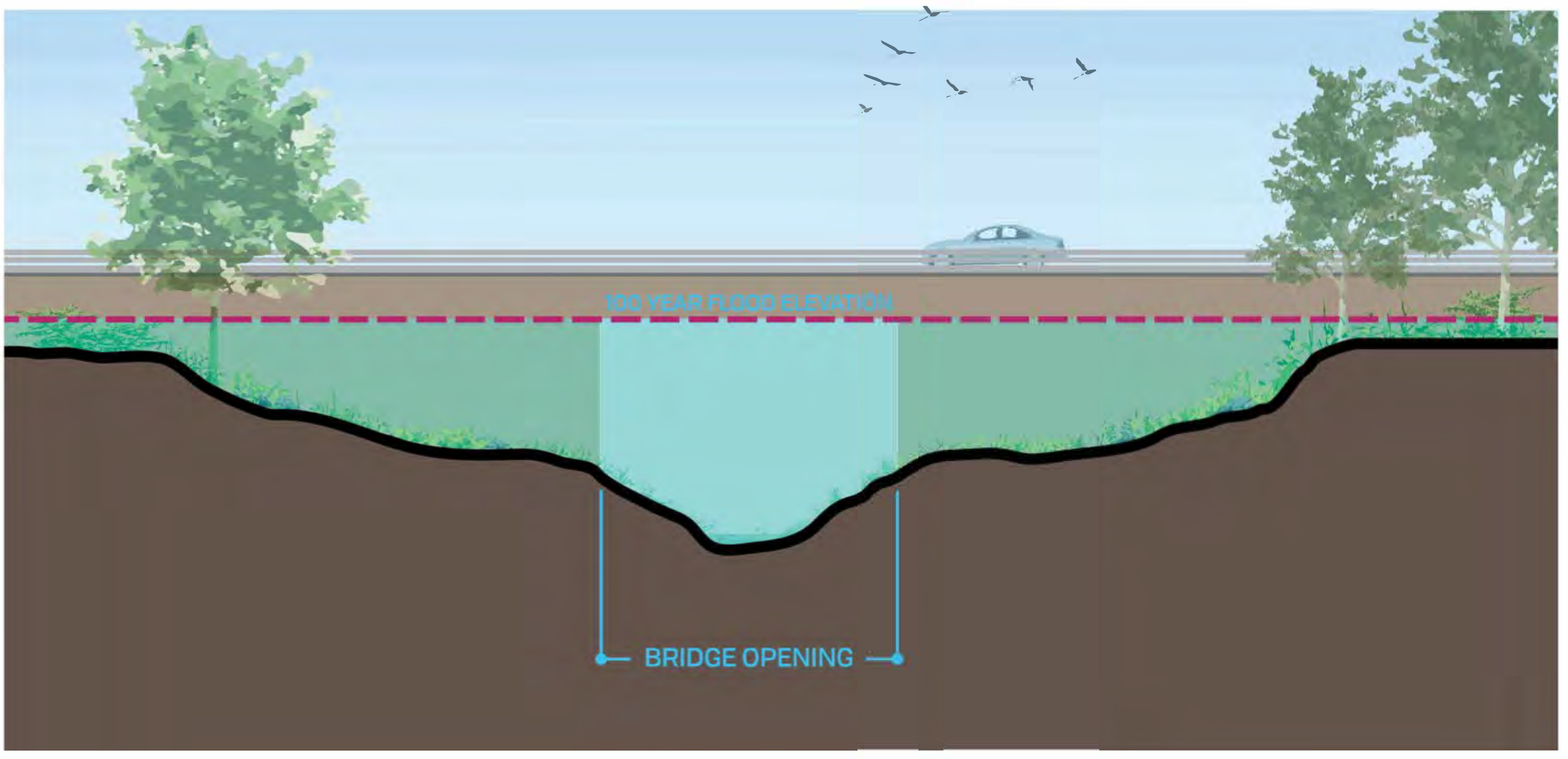
RYAN TOMKO, DEC

GARNELL WHITFIELD, NYS OEM

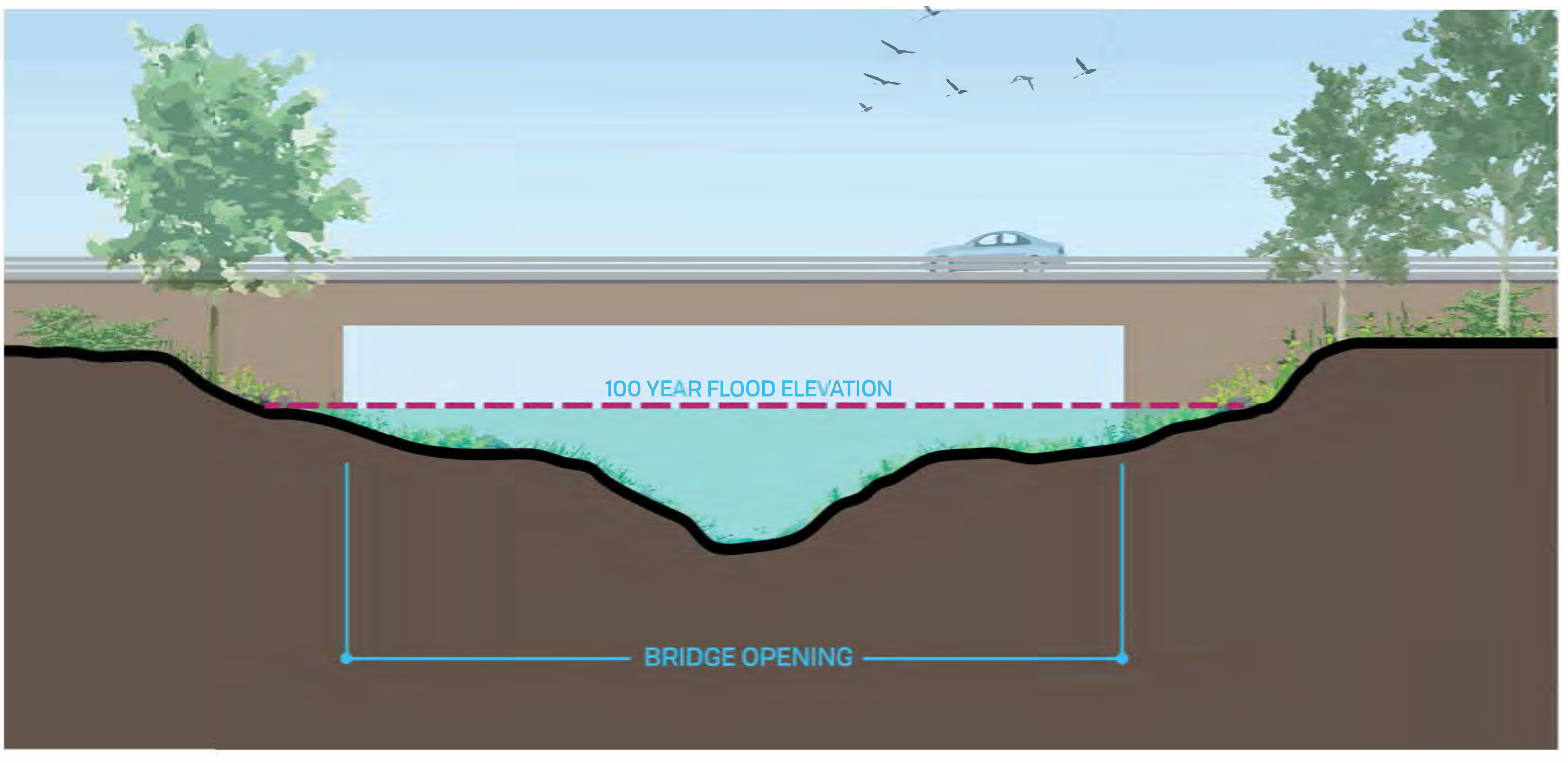
KATHERINE WINKLER, BUFFALO NIAGARA WATERKEEPER

DON ZELAZNY, NYSDEC

APPENDIX E
MITIGATION RENDERINGS

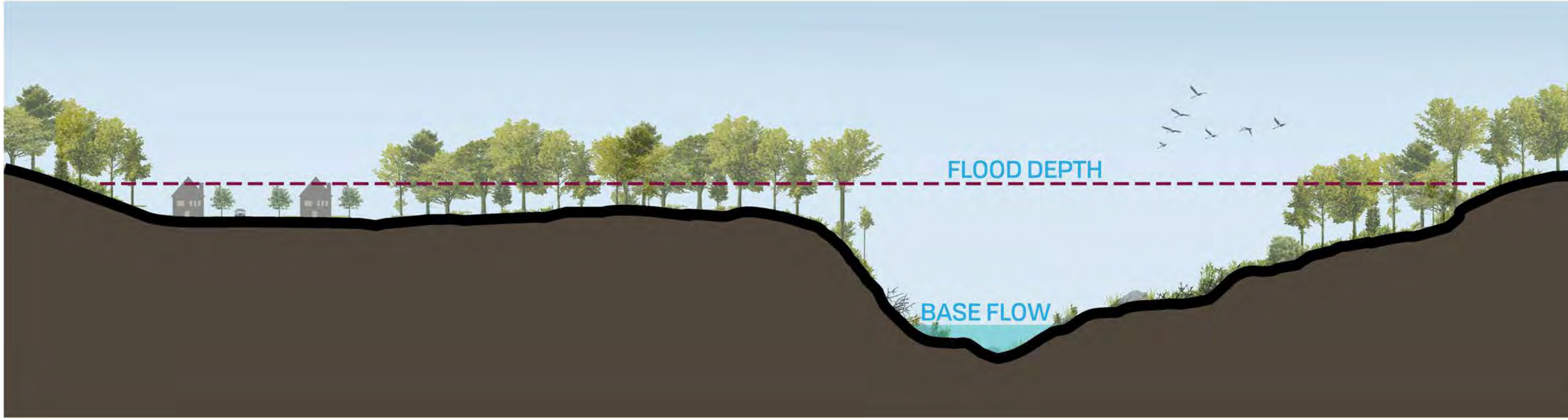


Existing Condition

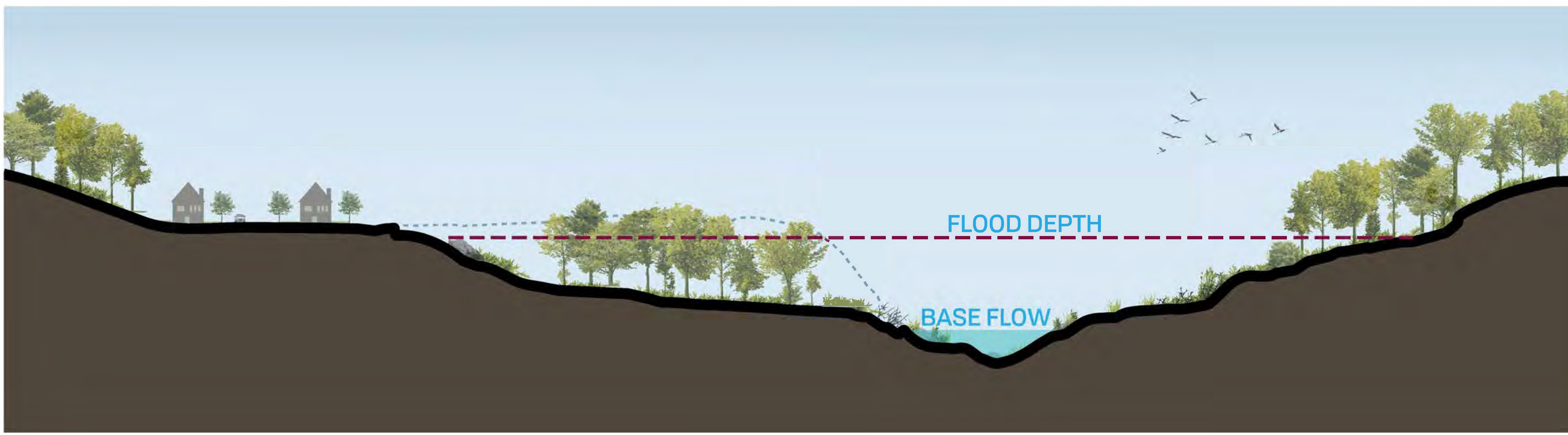


Future Condition

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.