RESILIENT NEW YORK FLOOD MITIGATION INITIATIVE

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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
BDF	Basin Development Factor
CDBG	Community Development Block Grants
CFA	Consolidated Funding Applications
CFS	Cubic Feet per Second (ft^3/s)
CRISSP	Comprehensive River Ice Simulation System
CRRA	Community Risk and Resiliency Act
CSC	Climate Smart Communities
CWSRF	Clean Water State Revolving Fund
DA	Drainage Area
DHS	Department of Homeland Security
DPW	Division of Public Works

ECDEP	Erie County Department of Environment and Planning
ECDHSES	Erie County Department of Homeland Security and Emergency Services
ECSWCD	Erie County Soil and Water Conservation District
EL	Average Main Channel Elevation
EPA	Environmental Protection Agency
EPG	Engineering Planning Grant
ESD	Empire State Development Corporation
EWP	Emergency Watershed Protection
FDD	Freezing Degree-Day
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIA	Federal Insurance Administration
FIS	Flood Insurance Study
FMA	Flood Mitigation Assistance
FT	Feet (ft)
GIS	Geographic Information System
GSE	Gomez & Sullivan Engineers
H&H	Hydrologic and Hydraulic
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HMA	Hazard Mitigation Assistance
HSGP	Homeland Security Grant Program
HUD	Department of Housing and Urban Development
IA	Impervious Surface Percentage
LF	Linear feet (lf)
MAP	Mean Annual Precipitation
NAVD 88	North American Vertical Datum of 1988
NFF	National Flood Frequency Program
NFIP	National Flood Insurance Program
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
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
NYSOEM	New York State Office of Emergency Management
NYSOGS	New York State Office of General Services
OBG	OBG, Part of Ramboll
PDM	Pre-Disaster Mitigation
RC	Circularity Ratio
RE	Elongation Ratio
RF	Form Factor
RF	Radio Frequency
RI2	2-hour/2-year Rainfall Intensity
RICEN	River Ice Simulation Model
RL	Repetitive Loss
ROM	Rough Order of Magnitude
SH	Basin Shape Index

SL	Main Channel Slope
SQ MI	Square Miles (mi^2)
SRL	Severe Repetitive Loss
ST	Basin Storage
USACE	United States Army Corps of Engineers
USGS	United States Geologic Service
USSCS	United States Soil Conservation Service
WQIP	Water Quality Improvement Project
WRI	Water Resources Investigations
WSP	Water-Supply Paper

INTRODUCTION

HISTORICAL INITIATIVES

Flood mitigation has historically been an initiative in western New York and in the Cayuga Creek watershed. In response to periodic and repetitive flood losses along Cayuga Creek, the United States Soil Conservation Service (USSCS) started a program for farmland treatment from 1946 to 1963, designed to reduce runoff and erosion from farms and stabilize channel banks in the Village of Lancaster. The conservation practices instituted by this program are still being used today by many landowners (FIA 1979).

In 1949, the United States Army Corps of Engineers (USACE) constructed a flood control project in the Villages of Lancaster and Depew in Erie County, NY. The project was designed for a peak discharge of 18,000 cubic feet per second (cfs) with an additional two feet of freeboard. Construction and improvements included: channel enlargement with minor straightening, an 8,300 linear foot (lf) earth dike, a 200-lf concrete-faced steel sheet pile wall, raising of Broadway and Aurora Street bridges, internal drainage system along Broadway including a pump station, and miscellaneous alterations to existing storm sewers (USACE 1979). In 1951, construction of flood control levees was completed in the Village of Lancaster (FEMA 2019b).

In 1982, construction was completed on a flood control project approved by the USACE on Cayuga Creek in the town of Cheektowaga, Erie County, NY, from the eastern edge of the Union Road bridge to approximately 1,000 ft upstream. The project was designed for a peak discharge of 14,700 cfs, which is equivalent to the 1% annual-chance flood event. Construction and improvements included: a 690-ft reinforced concrete inverted T-wall, 960 ft of embankment protection with 27-in riprap and a concrete curb, a 525-ft transverse levee , a 350-ft concrete gravity wall, installation of 280 ft of 18-in CMP culvert, and 1,000 ft of bank clearing, mulching and seeding, demolition, and removal of buildings (NYSDEC 2011).

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.) and right-sized bridges and culverts to lower flood stages 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. Local floodplain regulations should be consistent with the National Flood Insurance Program (NFIP) and FEMA regulations, and should involve a floodplain coordinator and a site plan review process for all proposed developments. This review should determine if the proposed development could impact the floodplain or floodway, and should not allow any fill in the floodplain or floodway of any watercourse.

RESILIENT NY INITIATIVE

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

The New York State Department of Environmental Conservation (NYSDEC) and Office of General Services (NYSOGS) implemented the studies for the Resilient NY Initiative. 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 identified the causes of flooding within each watershed and developed, evaluated, and recommended effective and ecologically sustainable flood and ice jam hazard mitigation projects. Proposed flood mitigation measures were identified and evaluated using hydrologic and hydraulic modeling to quantitatively determine flood mitigation recommendations that would result in the greatest flood reduction benefits. In addition, the flood mitigation studies incorporated the latest climate change forecasts and assessed ice jam hazards where jams have been identified as a threat to public health and safety.

The goals of the Resilient NY Initiative were 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 and where applicable, include a focus on ice-jam hazards

The overarching purpose is to recommend a suite of flood and, if applicable, ice-jam mitigation projects that local municipalities can undertake to make their community more resilient to future flood. The projects should be affordable, attainable through grant funding programs, able to be implemented either individually or 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 Cayuga Creek began in March of 2019 and is planned to be completed in early 2020.

DATA COLLECTION

INITIAL DATA COLLECTION

Hydrological and meteorological data were obtained from readily available state and federal government databases, including orthoimagery, Flood Insurance Rate Maps (FIRM), streamflow, precipitation, and 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, United States Geologic Service (USGS) *FutureFlow Explorer* v1.5 (Burns et al. 2015) and *StreamStats* v4.3.1 (Ries et al. 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 a Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) using USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) to predict creek stage at potential future high-risk areas and evaluate the effectiveness of flood mitigation strategies. These studies were obtained and used, all or in part, as part of this effort. Appendix A is a summary of the data and reports collected.

PUBLIC OUTREACH

An initial project kickoff meeting was held on July 16, 2019, with representatives of the NYSDEC, NYSOGS, Office of Emergency Management (OEM), OBG Part of Ramboll (OBG), Gomez & Sullivan Engineers (GSE), Highland Planning, USACE, Town of West Seneca, Town of Amherst, Town of Concord, Erie County Soil and Water Conservation District (ECSWCD), Erie County Department of Environment and Planning (ECDEP), Erie County Department of Homeland Security and Emergency Services (ECDHSES), and the Buffalo-Niagara Waterkeepers. At the project kickoff meeting, project specifics including background, purpose, funding, roles, and timelines were discussed (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 future flood risk assessments. Additional project meetings will be planned to include a summary of study procedures, recommended flood mitigation measures, and the results of H&H modeling.

FIELD ASSESSMENT

Following the initial data gathering and agency meetings, field staff from OBG undertook field data collection efforts with special attention given to areas deemed to be high-risk areas as identified in the initial data collection process. Initial field assessment of Cayuga Creek was 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 bridge and culvert inspections, 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.

WATERSHED CHARACTERISTICS

STUDY AREA

The Cayuga Creek watershed study area lies within Erie County, NY encompassing the areas between the Towns of Cheektowaga and Alden. The creek flows in a general northwestern direction with headwaters near the Town of North Java, and passes through the Towns of Sheldon, Bennington, Marilla, Alden, Lancaster, Cheektowaga, West Seneca and the Villages of Depew and Lancaster before joining Buffalo Creek to form the Buffalo River (Figure 1). As one of the three main tributaries that make up the Buffalo River, Cayuga Creek has the smallest drainage area when compared to the other tributaries, Cazenovia and Buffalo Creeks (USACE 1978). Within the Cayuga Creek watershed, the area between the Towns of Lancaster and Alden were chosen as target areas due to their historical flood records and the hydrologic conditions of the creek. Figures 2 and 3 depict the stream stationing along Cayuga Creek in Erie County, NY, and the study area in the Towns of Cheektowaga and Lancaster, respectively.

WATERSHED LAND USE

The Cayuga Creek basin is largely comprised of cultivated crops and hay/pasture (39%) and forested lands (33%) in the middle and upper portions of the basin, while the lower reaches are developed lands (17%) as the creek approaches the confluence with Buffalo Creek. As the creek approaches the confluence with Buffalo Creek, the corridor is comprised primarily of heavily developed land due to the close proximity of the study area to the City of Buffalo (Yang et al. 2018).

GEOMORPHOLOGY

The Cayuga Creek floodplain is relatively narrow, with high banks on the south and relatively low banks on the north. The floodplain consists of a series of nearly level plains rising in a series of steps to the north. During the final stages of the last glaciation, the lower reaches of the course of Cayuga Creek, from the mouth to the Village of Lancaster, was altered by the northward retreat of the ice front to produce the western deflection common to many streams and rivers in western New York. The upper reaches of the creek border the northern edge of the Alleghany Plateau, where high water velocities cause erosion of the overbanks due to channel banks lacking wooded vegetation, such as shrubs and trees. The eroded material is then deposited downstream on the Erie Plain where the creek channel widens, and water velocities decrease. Erosional deposition is evidenced by shoals in the lower reaches of Cayuga Creek, which partially obstruct channel flow (USACE 1979).

Surficial deposits generally blanket the Cayuga Creek watershed study area and are a result of the Pleistocene glaciation. The deltaic and glacial lake deposits and alluvial sediment material have formed outcrop patterns visible in numerous locations throughout the channel. The bedrock material present in the creek channel at various locations consists of sedimentary formations most likely from the middle and upper Devonian age (USACE 1979).

Figure 4 is a profile adapted from the FEMA FIS profile plot for Cayuga Creek displaying streambed elevation versus channel distance from the confluence with Buffalo Creek (FEMA 2019b). Cayuga Creek has an average slope of 0.25% over the profile stream length of 24 miles. The creeks streambed lowers approximately 321 vertical feet over this reach from an elevation of 893 feet above sea level (NAVD 88) at the border of Erie and Wyoming Counties, to 572 feet above sea level at the confluence of Cayuga Creek and Buffalo River in West Seneca, NY.

The slope of Cayuga Creek is not uniform throughout its flow path. The upstream portion of the creek, from the headwaters to the confluence with Little Buffalo Creek, has an average slope of 35-ft per mile, while the lower reach, from the Village of Lancaster to the confluence with Buffalo Creek, has an average slope of 7.5-ft per mile. The difference in slope contributes to channel bank erosion in the upstream and concentrates runoff and sediment deposition in the lower reaches (USACE 1979).

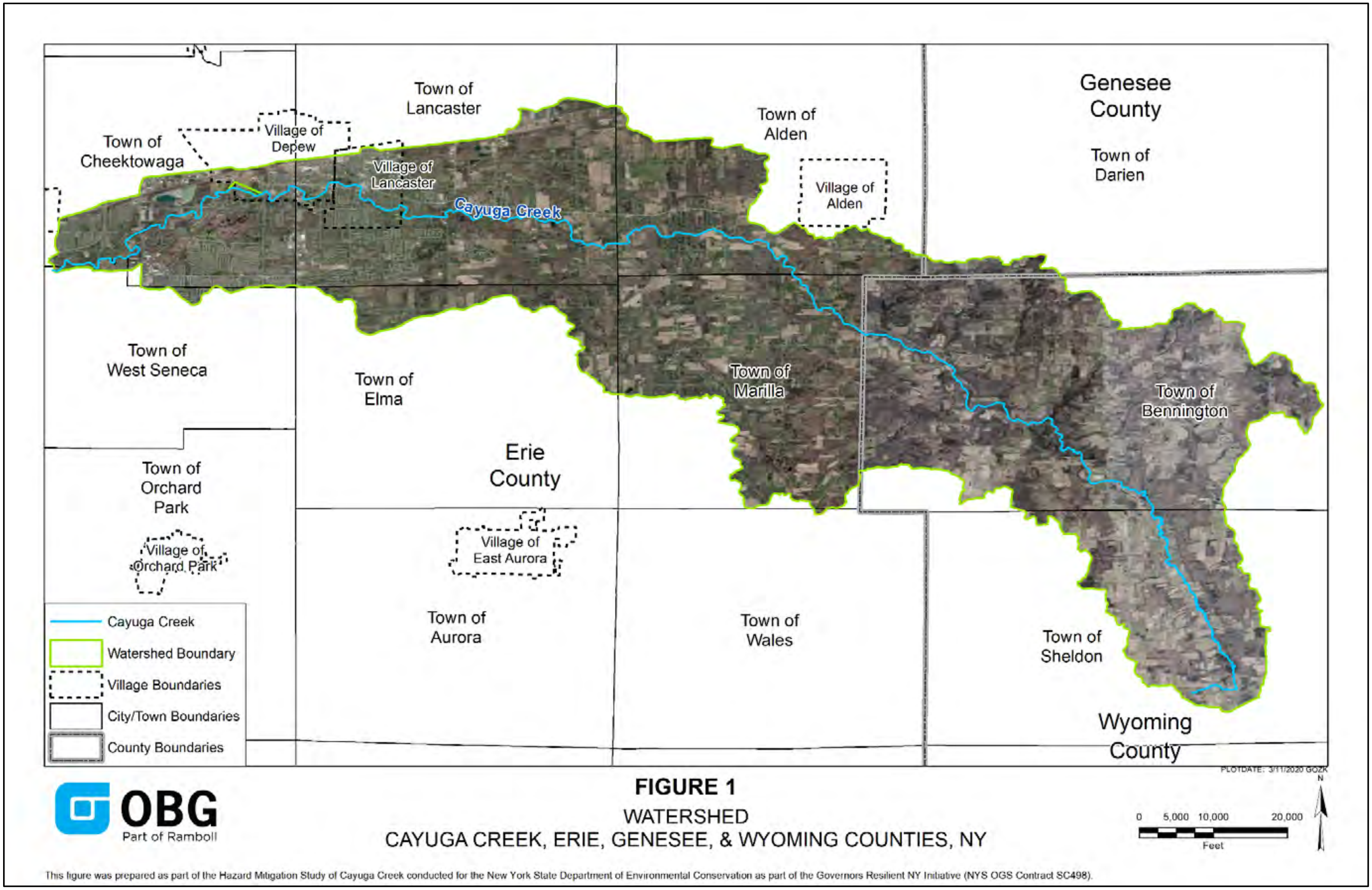

Figure 1. Watershed, Cayuga Creek, Erie, Wyoming, and Genesee Counties, NY.

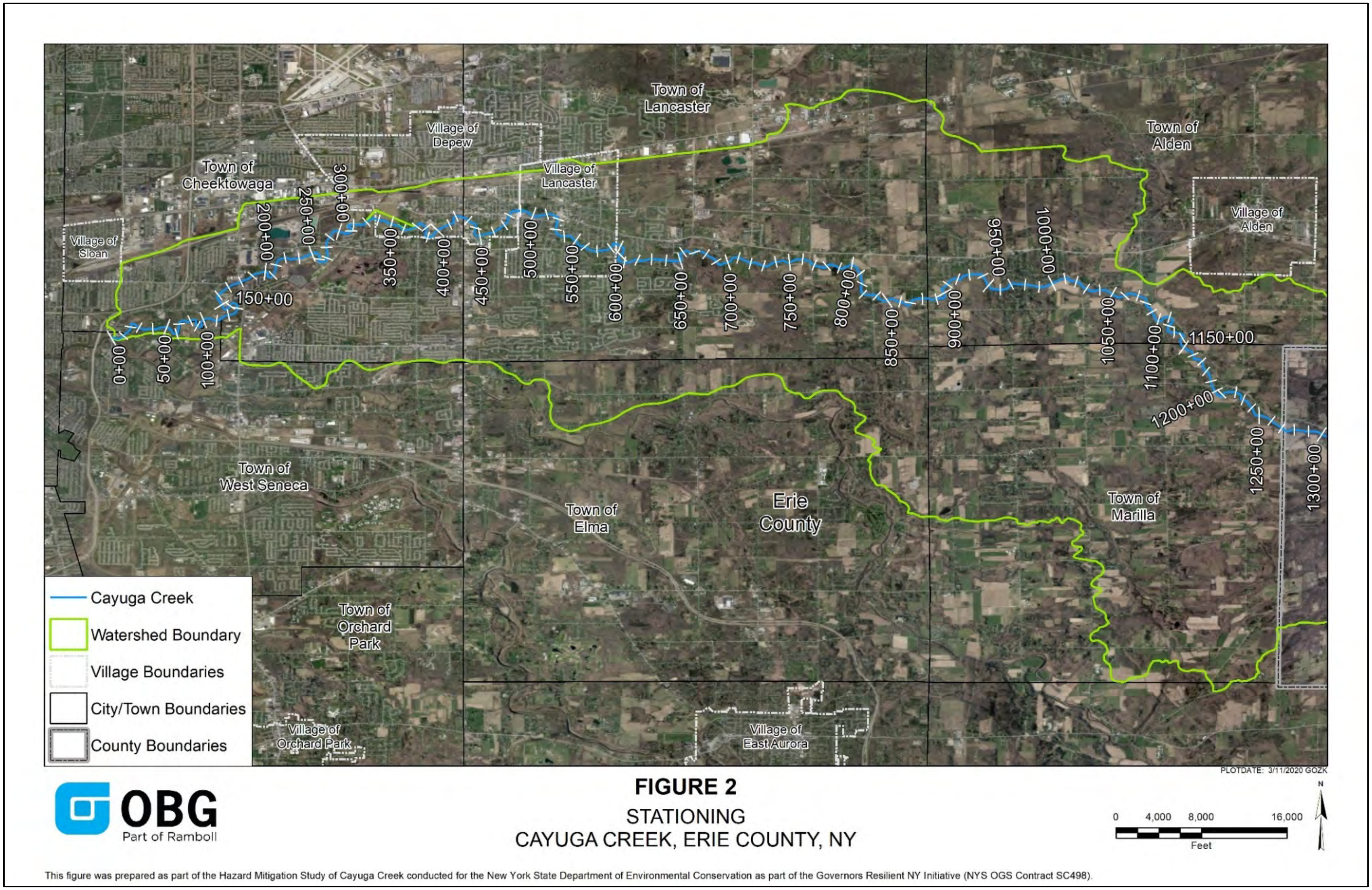

Figure 2. Stationing, Cayuga Creek, Erie County, NY.

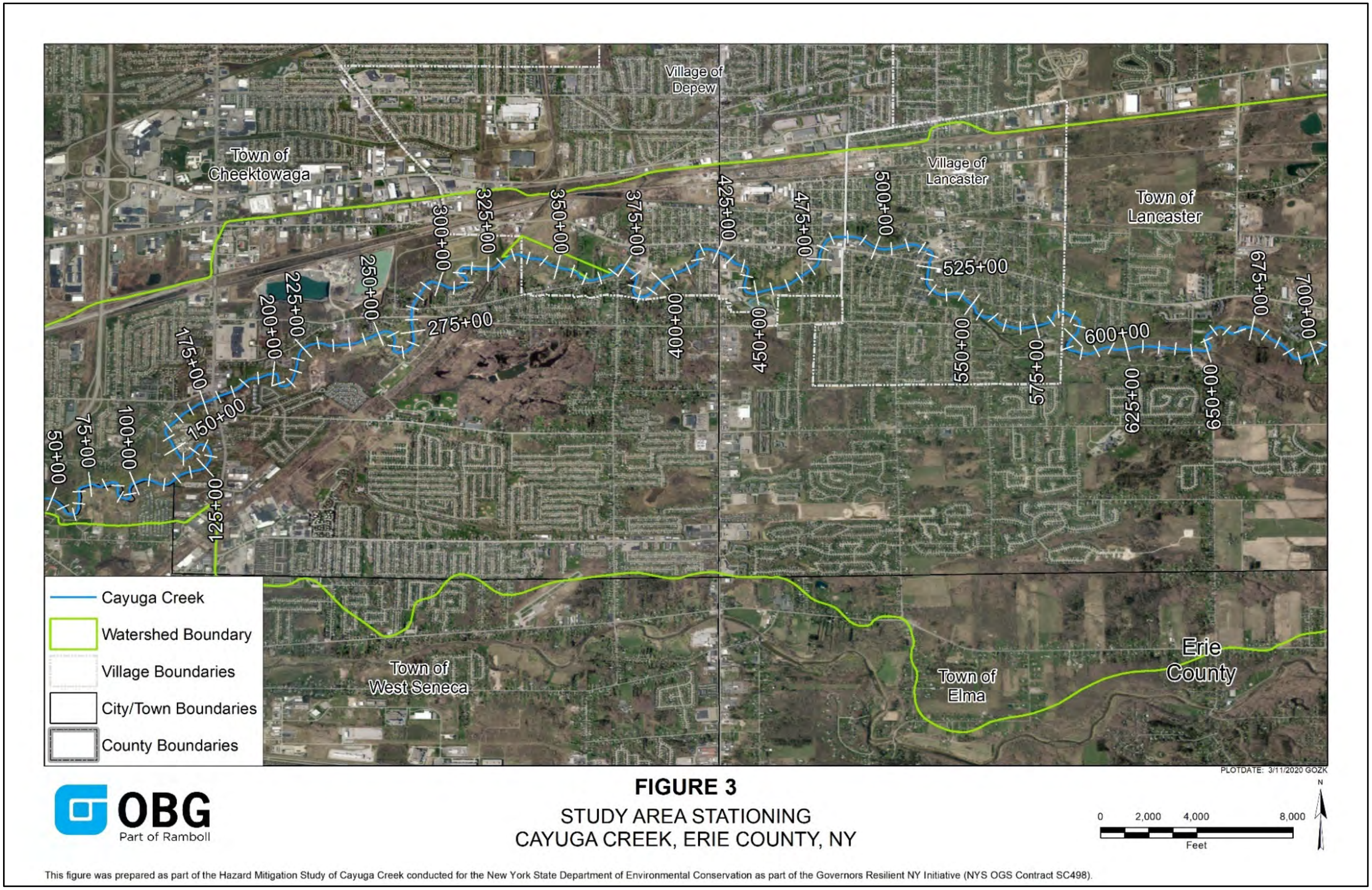

Figure 3. Study Area Stationing, Cayuga Creek, Erie County, NY.

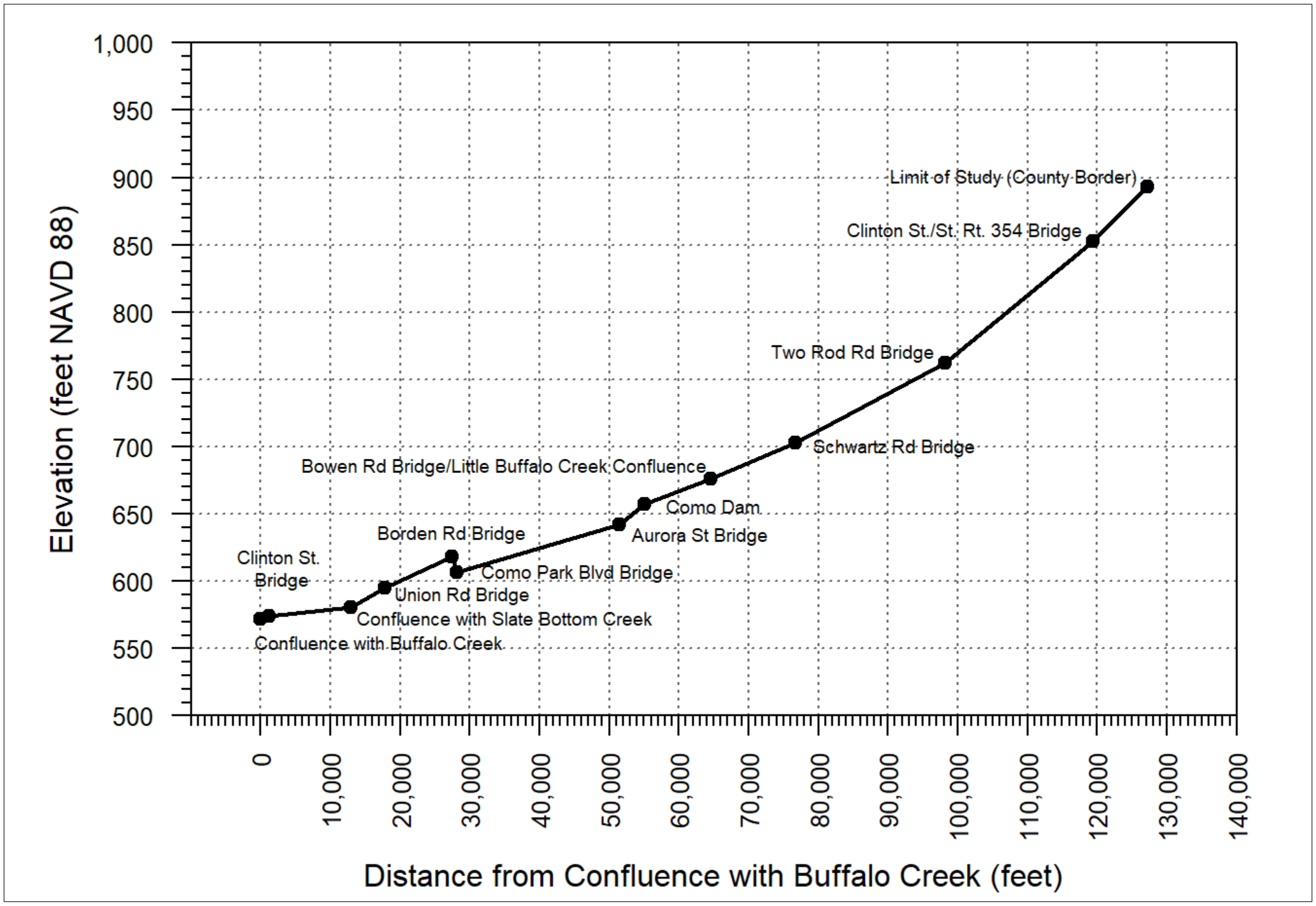

Figure 4. Cayuga Creek profile based on FEMA FIS ground surface elevation data (FEMA 2019b).

HYDROLOGY

Cayuga Creek drains an area of 128 mi^2 (square miles), is approximately 41 miles in length, and is located in the western portion of New York State. Numerous source tributaries join the main channel as the creek flows in a general northwest direction to the confluence with Buffalo Creek to form the Buffalo River. The two major tributaries are Slate Bottom and Little Buffalo Creeks, which join the creek downstream of Union Road bridge in the Town of Cheektowaga, and upstream of Como Lake Park in the Town of Lancaster, respectively (USACE 1978). After the confluence with Buffalo Creek, Cayuga Creek forms the Buffalo River and continues to flow westward another two miles to the confluence with Cazenovia Creek, and an additional six miles to its mouth at Lake Erie (USACE 1966).

Table 1 is a summary of the basin characteristic formulas and calculated values for the Cayuga Creek watershed, where A is the drainage area of the basin in square miles, B_L is the basin length in miles, and B_P is the basin perimeter in miles.

Table 1. Basin Characteristics Factors

(Source: USGS 1978)		
Factor	**Formula**	**Value**
Form Factor (R_F)	A / B_L^2	0.22
Circularity Ratio (R_C)	$4*\pi*A / B_P^2$	0.22
Elongation Ratio (R_E)	$2 * (A/\pi)^{0.5} / B_L$	0.53

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) values give an indication of topography. The higher the circularity ratio value, the lower the relief and less disturbance to drainage systems by structures within the channel. Elongation Ratio (R_E) values give an indication of ground slope, with values less than 0.7 correlating to steeper ground slopes and elongated basin shapes. Based on the basin characteristics calculations, the Cayuga 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 one USGS stream gaging station on Cayuga Creek, USGS 04215000 near Lancaster, NY. The USGS Gage near Lancaster, NY was used as the representative hydrologic dataset due to the robustness of the data collected at this site, and the extended time period over which the data was collected. This gage collected data for 80 years, beginning in 1937 and ending in 2018. The gage station near Lancaster provided the hydrologic data that was used by FEMA to develop regional drainage area/mean annual discharge curves for areas along Cayuga Creek (USGS 2019). An effective FEMA FIS for all of Erie County was issued on June 7, 2019 and included drainage area and discharge information for Cayuga Creek. Table 2 lists the FEMA FIS drainage area and peak discharges, in cubic feet per second, for various locations along Cayuga Creek (FEMA 2019b).

Table 2. FEMA FIS Peak Discharges						
(Source: FEMA 2019b)						
			Peak Discharges (cfs)			
Location	Drainage Area (sq. mi.)	River Station (ft)	10-Percent	2-Percent	1-Percent	0.2-Percent
Above confluence with Buffalo River	128	0+00	9,510	13,200	14,900	19,000
At Transit Road	112	423+00	9,260	12,600	14,100	17,700
At Village of Depew/Village of Lancaster corporate limits	111	487+00	9,230	12,600	14,100	17,600
Above Como Dam	101	554+50	8,730	11,700	13,000	16,100
At USGS Gage No. 04215000 near Lancaster, NY	96.4	637+00	8,460	11,300	12,500	15,400
Upstream of confluence with Little Buffalo Creek	69.5	647+00	6,099	8,147	9,012	11,103
At Town of Alden/Town of Lancaster corporate limits	59.1	885+00	4,950	7,020	7,970	10,300
Upstream of Two Rod Road and unnamed tributary	56	983+50	5,250	7,450	8,450	10,900
At towns of Alden, Marilla corporate limits	55	1148+00	5,300	7,000	7,700	9,400
Approximately 8,775 ft upstream of towns of Alden, Marilla corporate limits	50	1235+75	4,900	6,500	7,200	8,700
Approximately 10,575 ft upstream of towns of Alden, Marilla corporate limits	48	1253+75	4,700	6,300	7,000	8,500

The FEMA FIS peak discharges were determined in accordance with the procedures outlined in the publication by USGS entitled *Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites,* also referred to as *Water-Resources Investigations (WRI) Report 94-4002*. Based on WRI 94-4002, the variables governing the peak stream flows for each location are: drainage area (DA), basin storage (ST), mean annual precipitation (MAP), main channel slope (SL), average main channel elevation (EL), basin shape index (SH), 2-hour/2-year rainfall intensity (RI2), basin development factor (BDF), and impervious surface percentage (IA) (USGS 1994). The historical annual peak streamflow data, current to year 2005, was obtained from the USGS gages 04215000 near Lancaster, NY for Cayuga Creek, 04215500 at Ebenezer, NY for Cazenovia Creek, 04214200 at North Boston, NY for Eighteenmile Creek, 04218518 and 04218500 at Williamsville, NY for Ellicott Creek, and 04218000 at Rapids, NY for Tonawanda Creek. The USGS software program, *PeakFQ*, was run in accordance with the User's Manual for Program *PeakFQ*, Annual Flood Frequency Analysis using Bulletin 17B Guidelines for flood-frequency analysis of streamflow records, providing estimates of flood magnitudes and their corresponding variance for a range of annual exceedance probabilities (Flynn et al. 2006). The generalized skew coefficient and standard error values for each gage location where obtained from WRI 00-4022 (Lumia and Baevsky 2000). A regression analysis was then performed at each flow location in accordance with WRI 94-4002 to calculate flood discharges (USGS 2002). The regression analysis was performed utilizing the National Flood Frequency Program (NFF) to calculate discharges for the 10-, 2-, 1-, and 0.2% annual-chance flood. This program employs the New York regional rural regressions equations as established in WRI 90- 4197 (Lumia 1991). For urban settings, this program employs the nationwide urban equations as established in USGS Water-Supply Paper (WSP) 2207 (Sauer et al. 1983).

For this study, the FEMA FIS peak discharges were used for the model simulation analysis due to the recent updates to the discharge calculations, robustness of the methodology, and consensus over the reasonableness of the results when compared to the SIR 2006-5112 (Lumia et al. 2006) methodology among FEMA and the USGS (FEMA 2019b).

USGS *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).

The *StreamStats* application was selected to calculate bankfull statistics due to fact that the program uses 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. The regression equations relate drainage area to bankfull discharge and channel characteristics at gaged sites, which are then adapted to define bankfull discharge and channel characteristics at ungaged sites. 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. This regionally specific model of calculating bankfull statistics was determined to be more accurate when compared to a statewide (or pooled) model (Mulvihill et al. 2009). The bankfull width and depth of Cayuga 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 3 lists the estimated bankfull discharge, width, and depth at select locations along Cayuga Creek as derived from the USGS *StreamStats* program.

Table 3. Estimated Bankfull Discharge, Width, and Depth					
(Source: Ries et al. 2017)					
Location	**River Station (ft)**	**Drainage Area (sq. mi.)**	**Bankfull Discharge (cfs)**	**Bankfull Width (ft)**	**Bankfull Depth (ft)**
Clinton Street bridge	11+50	127	2,840	129	3.39
Confluence with Slate Bottom Creek	130+00	126	2,820	128	3.38
Como Park Boulevard bridge	280+50	111	2,530	122	3.28
Borden Road bridge	374+00	109	2,490	121	3.27
Aurora Street bridge	514+50	98.3	2,290	116	3.19
Confluence with Little Buffalo Creek	645+50	96.5	2,250	115	3.17
Two Rod Road bridge	982+50	57.3	1,450	92.2	2.79
Clinton Street/State Route 354 bridge (downstream dam)	1194+50	47.8	1,250	85.4	2.67

INFRASTRUCTURE

There are numerous dams along Cayuga Creek and its tributaries that interact with the flow of the creek. Of the seven dams along Cayuga Creek, three are purposed as recreational dams, while two are "other" purpose dams, one is an irrigation dam, and one dam is hydroelectric. There are two dams, Haungs and Lancaster County Club Dams, that have a hazard rating of class A or "low hazard" dam. The remaining dams along Cayuga Creek are classified as "negligible or no hazard" dams, or have not had a hazard rating assigned (NYSDEC 2019b).

Major bridge crossings over Cayuga Creek include Clinton Street (Route 354) in the Towns of West Seneca and Marilla; Union Road (Route 277) and Como Park Boulevard in the Town of Cheektowaga; Route 20 as Transit Road and Broadway in the Town of Lancaster; and Two Rod Road in the Town of Alden. Bridge lengths and surface widths for New York State Department of Transportation (NYSDOT) bridges were revised as of February 2019. Table 4 summarizes the NYSDOT bridge data for bridges that cross Cayuga Creek in Erie, Genesee, and Wyoming Counties in New York State with bankfull widths from the USGS *StreamStats* program (NYSDOT 2016; Ries et al. 2017).

Bankfull widths were derived from the USGS *StreamStats* software for bridge crossing locations that were considered high risk for potentially being constriction points based on the FEMA Flood Insurance Rate Maps. Table 4 indicates that in Erie County, NY, the Aurora Street and all three Pedestrian Path bridges in the Town of Lancaster are not wide enough to span the bankfull width of Cayuga Creek. In addition to these undersized bridges, many bridges throughout the Towns of Cheektowaga and Lancaster have central piers, which create an impediment to flow, especially during the winter months, leading to numerous reported ice jams along Cayuga Creek. Figure 5 displays the locations of the high and low-risk constriction point bridges that cross Cayuga Creek in Erie County, NY.

Table 4. NYSDOT Bridges Crossing Cayuga Creek

(Source: NYSDOT 2016; Ries et al. 2017)

County	Roadway Carried	River Station (ft)	NYSDOT BIN	Bridge Length (ft)	Surface Width[1] (ft)	Bankfull Width (ft)	Hydraulic Capacity (% Annual Chance)
Erie	Clinton Street	11+50	1046480	131	56	129	Greater than 0.2%
Erie	Union Road	178+00	1044280	130	72.8	122	Greater than 0.2%
Erie	Como Park Blvd	280+50	3328730	174	44	122	Greater than 0.2%
Erie	Rowley Road	283+50	3327000	153	32.7	122	Less than 10%
Erie	Borden Road	374+00	3327220	129	40	121	Up to 1%
Erie	Transit Road	423+00	1015560	132	58.1	121	Greater than 0.2%
Erie	Penora Street	464+00	3326880	171	36.6	120	Up to 1%
Erie	Broadway Street	478+50	1015570	130	59.1	116	Up to 1%
Erie	Aurora Street	514+50	3213250	110	35	116	Greater than 0.2%
Erie	Broadway Street	521+00	1015580	122	49.2	120	Greater than 0.2%
Erie	Lake Avenue	548+50	3213270	148.8	30	115	Greater than 0.2%
Erie	Pedestrian Path	558+50	3362140	105	9.1	115	Up to 1%
Erie	Pedestrian Path	565+50	3362180	52	7.9	115	Less than 10%
Erie	Pedestrian Path	572+50	3362190	91	7.7	115	Up to 1%
Erie	Bowen Road	645+50	3326870	134	40	115	Greater than 0.2%
Erie	Schwartz Road	767+00	3327330	163	31.9	122	Greater than 0.2%
Erie	Ransom Road	838+00	3327050	158	32	94.7	Greater than 0.2%
Erie	Town Line Road	885+00	3326980	111	30	93.7	Greater than 0.2%
Erie	Two Rod Road	982+50	1046590	111	27.6	92.2	Greater than 0.2%
Erie	Four Rod Road	1032+50	3362170	109	30	91.5	Greater than 0.2%

Table 4. NYSDOT Bridges Crossing Cayuga Creek

(Source: NYSDOT 2016; Ries et al. 2017)

County	Roadway Carried	River Station (ft)	NYSDOT BIN	Bridge Length (ft)	Surface Width[1] (ft)	Bankfull Width (ft)	Hydraulic Capacity (% Annual Chance)
Erie	Three Rod Road	1078+50	3327360	110	29.7	90.8	Greater than 0.2%
Erie	Clinton Street/NY-354	1194+50	1046510	125	32	85.4	Greater than 0.2%
Wyoming	Bullis Road/ Co. Rd 26	1316+00	3319650	116	28	83.2	No FEMA FIS Profile Data Available
Wyoming	Urf Road	1325+00	3319640	159	26.7	83	No FEMA FIS Profile Data Available
Wyoming	Reilein Road	1366+00	3319630	86	24.2	78.3	No FEMA FIS Profile Data Available
Wyoming	Folsomdale Road	1413+00	3319620	91	35	76.8	No FEMA FIS Profile Data Available
Wyoming	Schoellkopf Road	1452+00	3319610	104	14.5	76.2	No FEMA FIS Profile Data Available
Wyoming	Burrough Road	1541+00	3319600	96	26.7	72.3	No FEMA FIS Profile Data Available
Wyoming	Tooley Road	1652+50	3319590	52	24	54.8	No FEMA FIS Profile Data Available
Wyoming	Alleghany Road/NY-77	1704+00	1030030	56	33	50	No FEMA FIS Profile Data Available
Wyoming	Big Tree Road/US-20A	1855+50	1016120	39	30	46	No FEMA FIS Profile Data Available
Wyoming	Centerline Road	2035+00	3366440	24	22.5	30.7	No FEMA FIS Profile Data Available

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

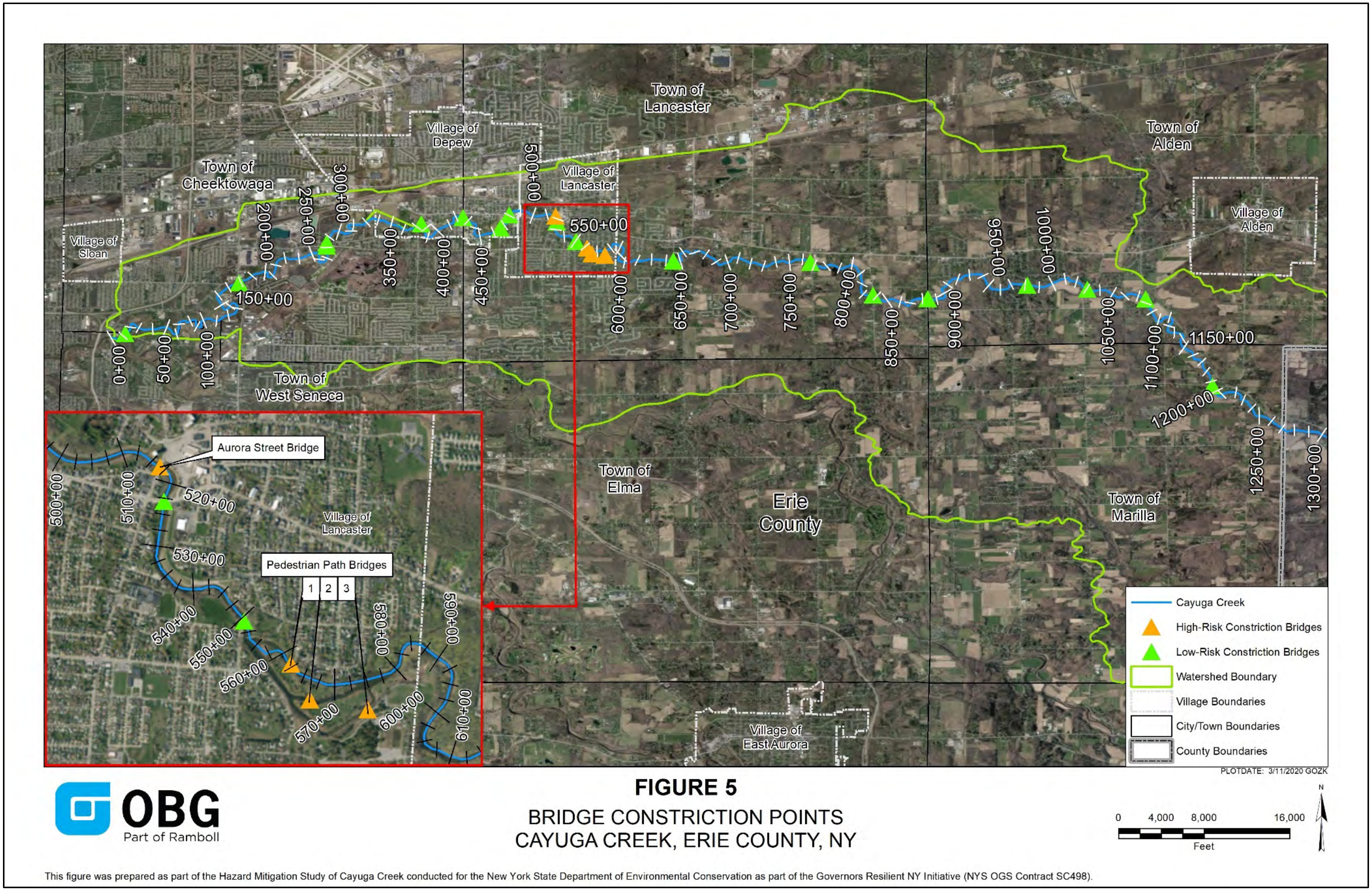

Figure 5. Bridge Constriction Points, Cayuga Creek, Erie County, NY.

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 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).

According to the NYSDOT bridge manual (2019) for Region 5, which includes Niagara, Erie, Chautauqua, and Cattaraugus Counties, normal bridges are required to maintain the minimum hydraulic design criteria for projects crossing waterways of 2-feet of freeboard over the 2% annual-chance flood elevation. For new and replacement bridges, current peak flows shall be increased to account for future projected peak flows based on the USGS *StreamStats* tool where current 2-percent 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).

In response to projected changes in climate, New York State passed the Community Risk and Resiliency Act (CRRA) in 2014. In the CRRA draft report (2018), the NYSDEC outlined infrastructure guidelines, most notably that the new freeboard recommendation for normal bridges is 2-feet of freeboard over the elevation of a flood with a 1% chance of being equaled or exceeded in a given year (i.e. base flood elevation) and 3-feet over for a critical structure (NYSDEC 2018). When compared to current guidelines, the new CRRA climate change recommended freeboard is based on the 1% annual-chance flood event water surface elevation, while the previous guidelines were based on the 2% annual-chance flood event. This is a higher standard for freeboard.

In assessing hydraulic capacity of the high-risk constriction point bridges along Cayuga Creek, the FEMA FIS profile of Cayuga Creek was used to determine the highest annual-chance flood elevation to flow under the low chord of a bridge (Table 4) (FEMA 2019b).

In addition, USGS *StreamStats* was used to calculate the bankfull discharge, and then compared to the annual-chance flood event discharges to determine the potential for backwater and flooding at these bridges. Table 5 summarizes the results from USGS *StreamStats* for the hydraulic capacity of the high-risk constriction point bridges along Cayuga Creek. Since the high-risk bridges' bankfull widths exceed their lengths, which when coupled with the fact that the bankfull discharges for each bridge is equivalent to an 80% annual-chance flood event or greater, the likelihood that relatively low to moderate flows potentially causing backwater and flooding at these bridges is fairly high.

Source: (Ries et al. 2017)			
Roadway Carried	**River Station (ft)**	**Bankfull Discharge (cfs)**	**Annual-chance Flood Event Equivalent**
Aurora Street	514+50	2,290	80-Percent
Pedestrian Path	558+50	2,260	80-Percent
Pedestrian Path	565+50	2,260	80-Percent
Pedestrian Path	572+50	2,260	80-Percent

CLIMATE CHANGE IMPLICATIONS

FUTURE PROJECTED DISCHARGE IN CAYUGA 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 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).

USGS *FutureFlow* Explorer v1.5 (https://ny.water.usgs.gov/maps/floodfreq-climate/) is discussed as a potential tool to project peak flows under various climate scenarios into the future. *FutureFlow* was developed by the USGS in partnership with the New York State Department of Transportation. This application is an extension for the USGS *StreamStats* map-based web application and projects future stream flows in New York State. The USGS team examined 33 global climate models and selected five that best predicted past precipitation trends in the region. The results were then downscaled to apply to all six hydrologic regions of New York State. Three time periods can be examined: 2024-2049, 2050-2074 and 2075-2099, as well as two Intergovernmental Panel on Climate Change (IPCC) greenhouse gas emission scenarios, termed "Representative Concentration Pathways" (RCP): RCP 4.5 and RCP 8.5. RCP 4.5 is considered a midrange-emissions scenario, and RCP 8.5 is a high-emissions scenario (Taylor et al. 2011; NYSDEC 2018).

In general, climate models are better at forecasting temperature than precipitation, and contain some level of uncertainty with their calculations and results. The USGS recommends using *FutureFlow* projections as qualitative guidance to see likely trends within any watershed and as an exploratory tool to inform selection of appropriate design flow. Current future flood projection models cannot provide accurate results for basins that extend across more than one hydrologic region in New York (NYSDEC 2018).

Based on the current future flood projection models, flood magnitudes are expected to increase in nearly all cases in New York State, but the magnitudes vary among regions. While the *FutureFlow* application is still being upgraded, it can be used with appropriate caution. Climate model forecasts are expected to improve and as they do, the existing regression approach can be tested and refined further (NYSDEC 2018).

The NYSDEC recommends that future peak flow conditions should be adjusted by multiplying relevant peak flow parameters by a factor specific to the expected service life of the structure and geographic location of the project. For Western New York, the recommended design-flow multiplier is 10% increased flow for an end of design life of 2025-2100 (NYSDEC 2018). Table 6 provides the projected future peak stream flows at select FEMA FIS locations using the NYSDEC CRRA design-flow multiplier.

Table 6. Projected Peak Discharges Using the NYSDEC CRRA Design Flow Multiplier

(Source: FEMA 2019b; NYSDEC 2018)

			Projected Peak Discharges (cfs)			
FEMA FIS Location	Drainage Area (sq. mi.)	River Station (ft)	10-Percent	2-Percent	1-Percent	0.2-Percent
Above confluence with Buffalo River	128	0+00	10,461	14,520	16,390	20,900
At Transit Road	112	423+00	10,186	13,860	15,510	19,470
At Village of Depew/Village of Lancaster corporate limits	111	487+00	10,153	13,860	15,510	19,360
Above Como Dam	101	554+50	9,603	12,870	14,300	17,710
At USGS Gage No. 04215000 near Lancaster, NY	96.4	637+00	9,306	12,430	13,750	16,940
Upstream of confluence with Little Buffalo Creek	69.5	647+00	6,709	8,962	9,913	12,213
At Town of Alden/Town of Lancaster corporate limits	59.1	885+00	5,445	7,722	8,767	11,330

Appendix G contains the HEC-RAS simulation summary sheets for the proposed and future condition simulations. The HEC-RAS model simulation results for the base condition model parameters using the future projected discharge values are similar to the base condition model output, with the only difference being future flow condition water surface elevations are 0.3 to 1.0-ft higher due to the increased discharges. Table 7 displays the change in water surface elevations for each annual-chance flood event at select FEMA FIS locations along Cayuga Creek using the HEC-RAS base and future condition simulations.

Table 7. Change in Water Surface Elevations using HEC RAS Base and Future Condition Simulations

(Source: FEMA 2019b; NYSDEC 2018; USACE 2016b)

			Water Surface Elevation (ft)			
FEMA FIS Location	Drainage Area (sq. mi.)	River Station (ft)	10-Percent	2-Percent	1-Percent	0.2-Percent
Above confluence with Buffalo River	128	0+00	+ 0.6	+ 0.7	+ 0.8	+ 0.9
At Transit Road	112	423+00	+ 0.6	+ 0.9	+ 0.9	+ 0.6
At Village of Depew/Village of Lancaster corporate limits	111	487+00	+ 0.5	+ 0.6	+ 0.8	+ 1.0
Above Como Dam	101	554+50	+ 0.3	+ 0.3	+ 0.3	+ 0.3
At USGS Gage No. 04215000 near Lancaster, NY	96.4	637+00	+ 0.3	+ 0.3	+ 0.4	+ 0.4
Upstream of confluence with Little Buffalo Creek	69.5	647+00	+ 0.5	+ 0.6	+ 0.6	+ 0.7
At Town of Alden/Town of Lancaster corporate limits	59.1	885+00	+ 0.3	+ 0.3	+ 0.3	+ 0.3

FLOODING CHARACTERISTICS

FLOODING HISTORY

Flooding along Cayuga Creek occurs almost annually, and generally in the late winter and early spring months due to rapid snowmelt and spring rains. The situation is compounded by restrictive bridge openings, low creek banks, and meandering channels, which cause ice jams along the stream channel, and continued development in the floodplain exposing greater numbers of assets to potential flood damages. Historically, the majority of flooding in Cayuga Creek occurred along the lower seven miles of the basin with major flooding in the vicinity of the Union Road bridge. Overbank flooding typically occurred immediately upstream of the bridge where there is a high concentration of residential and commercial development that became severely inundated with each major flooding event. Lesser flooding problems existed in the Como Park Lake area where nearby residents reported flooded basements on a near annual basis (USACE 1979).

Most major floods have occurred during the months of January to March. The greatest flood of historical record occurred in June 1937, while other recorded major flooding events occurred in March 1942, March 1955, March 1956, January 1959, March and June of 1972, January 1999, September 2000, December 2008, and January 2014. Minor flooding events also occurred in March 1904, January 1929, January 1962, March 1964, September 1967, December 1969, January 1975, January and July 1998, February 2002, March and December 2007, March 2009, January 2010, April 2011, and April, July, and November 2017. The June 1937 flood is generally considered to be the maximum of record and is the only major flooding event to have occurred during the summer months. Heavy rainfall was recorded throughout Western New York on June 17, and again during June 20-21. The rainfall of June 20-21 was centered in the eastern suburbs of Buffalo and fell on wet, saturated ground in a period of around six hours. The maximum recorded rainfall was 3.00 inches at the Buffalo Airport, 2.06 inches at the downtown Buffalo station, and 1.50 inches at South Wales. Damages were estimated to be around $124,000 in 1966 U.S. dollars (USACE 1979; NCEI 2019).

More recently on July 13, 2017, a convective complex moved across Western New York producing 2-4 inches of rain in a short time period, which resulted in significant flash flooding throughout the region. The flash flooding resulted in numerous road closures and water rescues as some residents were trapped inside their homes due to the rapidly rising flood waters. The USGS gage on Cayuga Creek at Lancaster reported an 11.06-foot crest, while the flood stage crest for the station is eight feet. This was the highest crest on record and highest warm season crest for the gage on Cayuga Creek. Reported damages associated with this event totaled $245, 000 in Western New York (NCEI 2019).

FEMA Flood Insurance Rate Maps are available for Cayuga Creek from FEMA. Figures 6, 7, and 8 display the floodway and 1- and 0.2% annual-chance flood event boundaries for Cayuga Creek as determined by FEMA in the Towns of Cheektowaga, Lancaster, and Alden/Marilla in Erie County, NY, respectively. The maps indicate that flooding generally occurs in the Towns of Cheektowaga, Lancaster, and Alden. The Town of Lancaster has experienced the largest impacts from flooding along Cayuga Creek with the areas in the vicinity of the Union Road bridge experiencing repetitive losses due to flood damages from ice jams along the creek (FEMA 2019a).

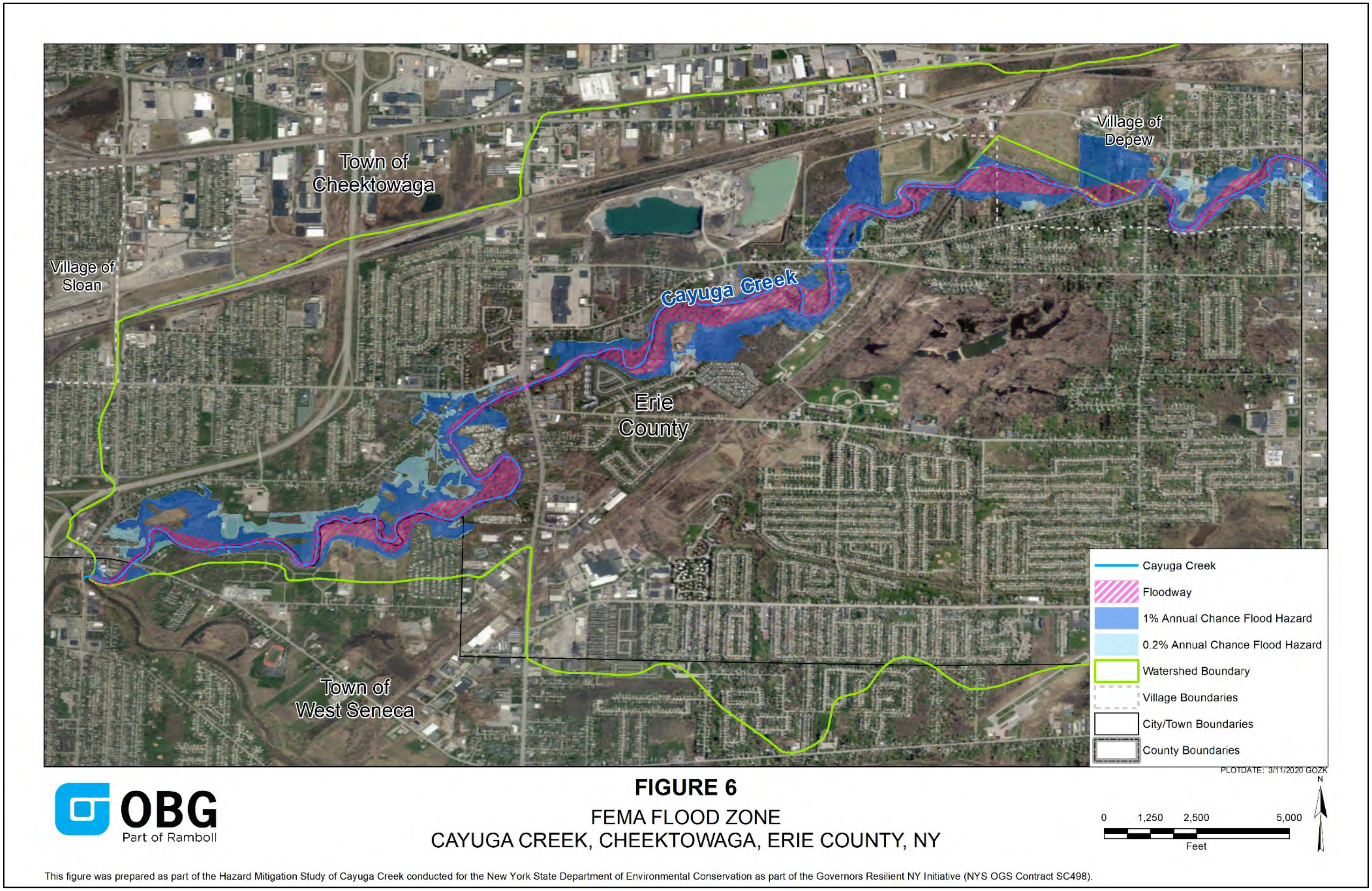

Figure 6. FEMA Flood Zones, Cayuga Creek, Town of Cheektowaga, Erie County, NY.

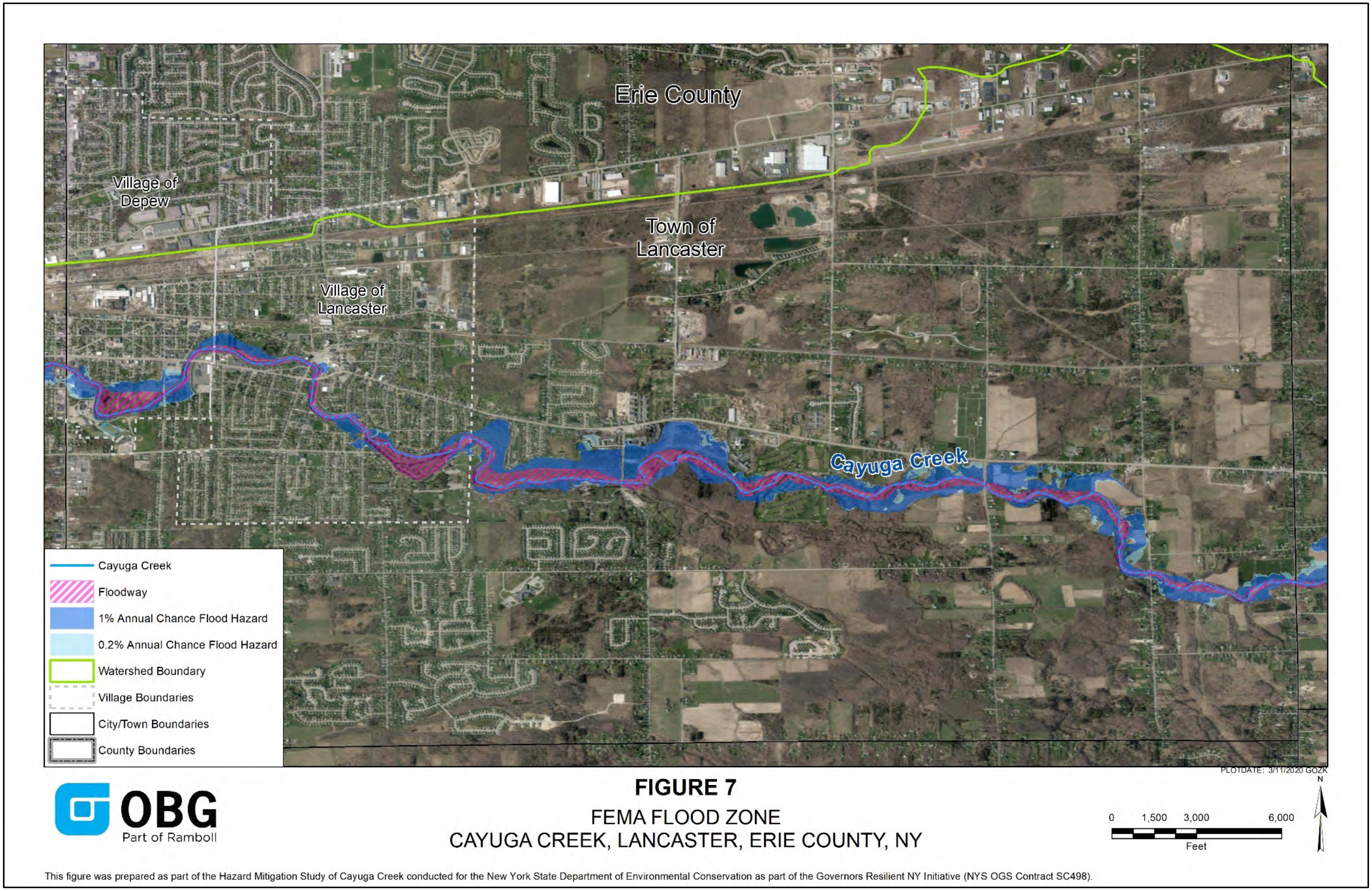

Figure 7. FEMA Flood Zones, Cayuga Creek, Town of Lancaster, Erie County, NY.

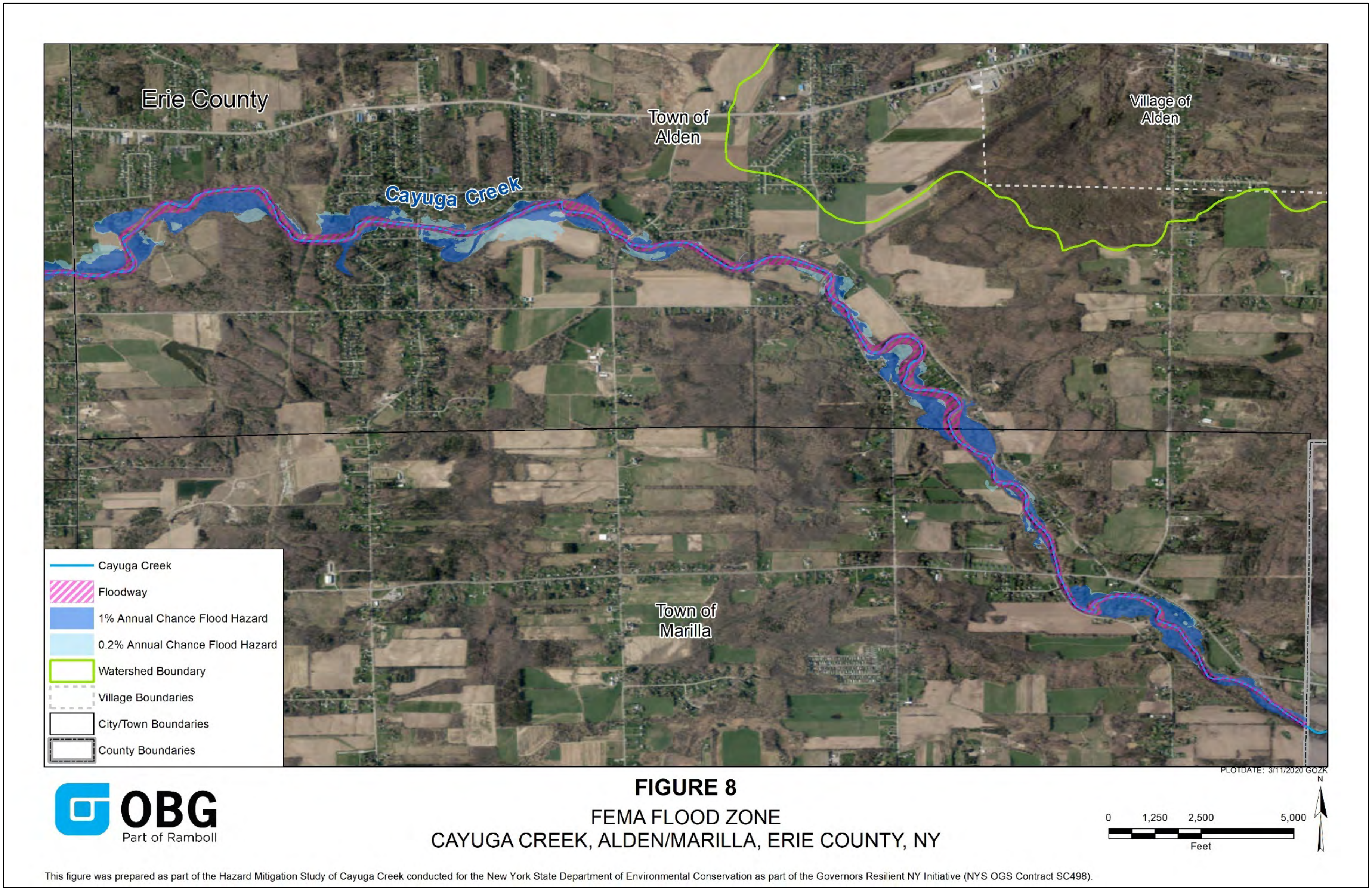

Figure 8. FEMA Flood Zones, Cayuga Creek, Towns of Alden/Marilla, Erie County, NY.

FLOOD MITIGATION ANALYSIS

The USACE performed an analysis of ice effects on water surface elevations while preparing the *Detailed Project Report for Flood Management in Cayuga Creek Watershed* (1979). Their analysis, verified by field observations, concluded that ice does effect water surface elevations in the creek channel, but the wide, flat, and relatively low channel banks upstream of the Village of Lancaster provide adequate areas for flood benches and ice storage that could reduce ice jamming potential in the highly developed lower reaches of Cayuga Creek (USACE 1979).

Hydraulic analysis of Cayuga Creek was conducted using the USACE HEC-RAS program. The HEC-RAS computer program was written by the USACE Hydrologic Engineering Center and is considered to be the industry standard for riverine flood analysis. The model is used to compute water surface profiles for one-dimensional, steady-state, or time-varied flow. The version of HEC-RAS used in this study was 5.0.7.

Water surface profiles are computed from one cross-section to the next by solving the one-dimensional energy 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.

Hydraulic modeling of Cayuga Creek in the Towns of Cheektowaga, Lancaster, and West Seneca, and the Villages of Depew and Lancaster were completed by FEMA in 2009. The H&H data for Cayuga Creek was produced using the HEC-RAS modeling software. The model domain began at the confluence of Cayuga Creek with Buffalo Creek in the Town of West Seneca, NY (river station 0+00), and extends eastward through the Town of Cheektowaga, ending upstream of the Ransom Road bridge in the Town of Lancaster (river station 884+33), which included the target study area. Using the Cayuga Creek model data, a base condition model was developed without any changes to the original H&H data and run in HEC-RAS. Once the base condition model was successfully developed, it was then compared to past flood events with known water surface elevations and the effective FIS profiles to validate the model. The base condition model did not need any channel geometry updates due to the recent completion of the FEMA FIS for Erie County, NY, and the fact that the study area reaches were modeled using updated data.

After the base condition model had been verified, it was 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 to determine which flood mitigation proposals should be recommended for the project. The flood mitigation strategies that were modeled were:

<u>Town of Cheektowaga/Village of Depew</u>

- Removing the inactive railroad bridge upstream the Rowley Road bridge adjacent to the landfill and recycling centers
- Removing the Rowley Road bridge
- Increasing bridge length of the Borden Road bridge
- Installation of a flood bench upstream of the inactive railroad bridge
- Installation of a flood bench downstream of the Penora Street bridge

Town and Village of Lancaster

- Increasing bridge length of the Bowen Road bridge
- Removing sediment and sand bars under and around the Bowen Road bridge
- Installation of a flood bench upstream of the confluence of Cayuga Creek with Little Buffalo Creek

COST ESTIMATE ANALYSIS

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

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

For mitigation alternatives where increases in bridge 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. Cost estimates were performed based on projects determined to be constructible and practical.

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

In addition, costs associated with land acquisition, including costs for survey, appraisal, and engineering coordination, were not included in the ROM cost estimates for any mitigation measure due to the variability of estimating land costs.

ICE JAM ANALYSIS

ICE JAM FORMATION

An ice jam 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 drops more, 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 lead to ice jams and ice jams effects both upstream and downstream water levels.

An existing ice jam can break-up and travel downstream 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).

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 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.

ICE-JAM PRONE AREAS

The Cayuga Creek watershed is susceptible to ice-jam formation and consequent ice jam related flooding. Since 1959 to 2014, there have been eight break-up ice-jam flooding events recorded out of 39 reported flood events that occurred during the winter that are registered in the USACE ice jam data base on Cayuga Creek (CRREL 2019). The most recent ice jam event on Cayuga Creek occurred on January 11, 2014, when above normal temperatures caused snow and ice to thaw after days of sub-zero temperatures, which resulted in an ice break-up in the Town of West Seneca, NY. Cayuga Creek crested at 9.5 ft of water depth, while flood stage, according to the National Weather Service (NWS), at the USGS gage is 8 ft. Minor flooding in low-lying areas along the creek near, and in the Town of Lancaster were reported, but no damage figures are available (CRREL 2019).

Based on historical flood reporting's found on news media on the internet and through public outreach, the Town of Lancaster and Village of Depew were identified to be the most adversely affected communities by wintertime flooding in the Cayuga Creek basin. Ice-jam flooding on Cayuga Creek occurs primarily in the following locations:

- Town of Lancaster at the confluence of Cayuga Creek and Little Buffalo Creek upstream of the Bowen Road bridge
- Village of Depew in the vicinity of the inactive railroad bridge and the landfill and recycling facilities
- Village of Depew in the vicinity of the Transit Road bridge upstream of the Broadway (US-20) bridge
- Historically, the Union Road bridge, however channel improvements have minimized the occurrence of flooding in this area (NYSDEC 2019a)

The target area for this report focused on the Town of Lancaster and Village of Depew and, more specifically, the historically high-risk areas listed above. These areas are highly vulnerable to flooding as a result of infrastructure, development, and prior channelization projects along Cayuga Creek. The recent ice-jam flooding of 2014 highlights the vulnerability of this reach of Cayuga Creek to flooding.

High Risk Area #1: Village of Depew Old Division of Public Works Landfill/Rowley Rd Bridge, Depew, NY

High Risk Area #1 is the reach between the Rowley and Borden Road bridges in the Village of Depew at river stations 275+00 to 375+00. This reach contains an inactive railroad bridge crossing over Cayuga Creek, and a channelized right bank with concrete to increase flow around a near a 180° bend in the creek as the channel approaches the former Village of Depew Division of Public Works (DPW) landfill site (Figure 9).

The effective FEMA FIRMs show that the inactive railroad bridge constricts the flow of Cayuga Creek causing backwater flooding upstream of the bridge. The bridge low chord elevation is equal to the 0.2% annual-chance flood event water surface elevation. Downstream of the railroad bridge, there is a near 180° bend followed immediately by a near 90° bend in the creek channel that further acts to constrict flow. The near 180° bend has been channelized with concrete bends, which increases the velocity of the water as it flows through this area. As the water flows downstream to the Rowley Road bridge, the velocity decreases causing the water to rise. The Rowley Road bridge low chord elevation is equal to the 10% annual-chance flood event water surface elevation. Flood events greater than the 10% annual-chance cause backwater flooding and flow overtop the bridge. Flooding and increased water flow has caused channel bank destabilization and erosion of Cayuga Creek in areas near the bridge (USACE 2016b; NYSDEC 2019a).

High Risk Area #2: Broadway/US-20 Shopping Plaza and Residences, Lancaster, NY

High Risk Area #2 is the reach between the Broadway (US-20) bridge downstream of the Como Park dam to the Penora Street bridge at river stations 425+00 to 510+00. This reach contains a large number of commercial and residential properties, including the D&L Shopping Plaza and the Village of Lancaster water tower. Both the left and right banks of Cayuga Creek within this reach have been channelized with stone and rock riprap along the banks and levees, protecting the shopping plaza on the left bank and residences on the right bank (Figure 10).

The effective FEMA FIRMs show that of the four bridges within this reach, all constrict flow within the channel, with the Penora Street and Broadway (downstream) bridges constricting flow and causing backwater flooding upstream, and hydraulic jumps downstream of both bridges. Both bridge low chord elevations are below the 0.2% annual-chance flood event water surface elevation. The levees and channelized banks constrict high flows and increase their velocities forcing water downstream. As these flows decrease velocity, water depths rise, which could potentially lead to flooding downstream.

High Risk Area #3: Confluence with Little Buffalo Creek, Lancaster, NY

High Risk Area #3 is the confluence of Cayuga Creek with Little Buffalo Creek in the Town of Lancaster, NY at river stations 600+00 to 685+00. The confluence is located immediately upstream of the Bowen Road bridge as Cayuga Creek enters the Como Lake Park (Figure 11).

The effective FEMA FIRMs show that the Bowen Road bridge constricts the flow of Cayuga and Little Buffalo Creeks as they join just downstream of the bridge. This constriction, coupled with the near 90^{o} bend in the creek channel upstream of the bridge, causes backwater flooding upstream, and a hydraulic jump downstream of the bridge. During winter and early spring, ice flowing along the creek is constricted by the large pier of the bridge, which causes the ice to collect at the base of the pier and along the wingwalls and abutments of the bridge. As the ice builds, water flow in the creek channel is restricted and rises, which causes backwater to overflow the creek banks onto nearby streets, properties, etc., including the Grove Shelter and the neighborhoods along Logan Lane and the Bell Towers Village Condos on Bowen Road (NYSDEC 2019a; FEMA 2019a).

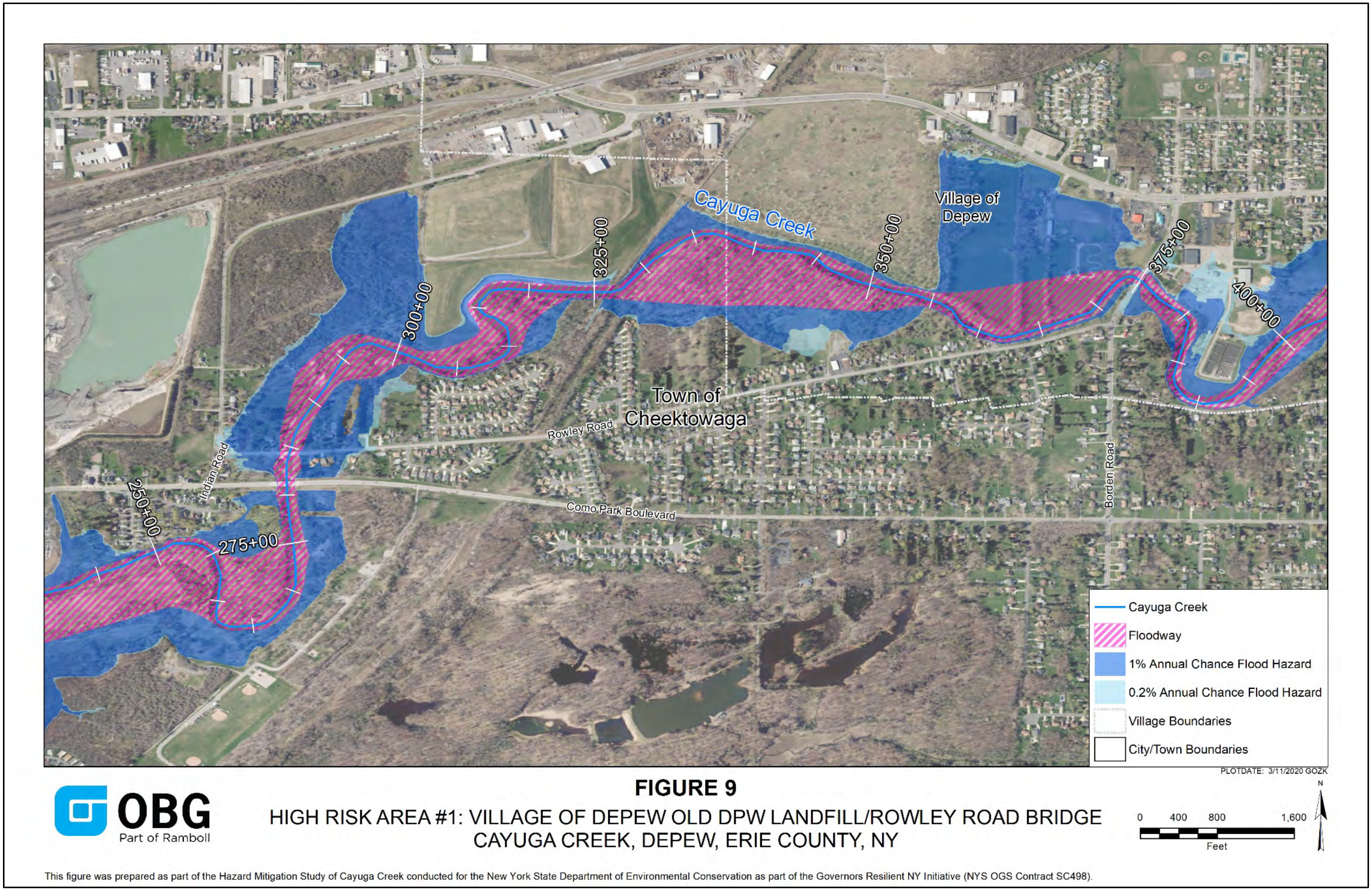

Figure 9. High Risk Area #1: Old DPW Landfill/Rowley Road Bridge, Cayuga Creek, Depew, Erie County, NY.

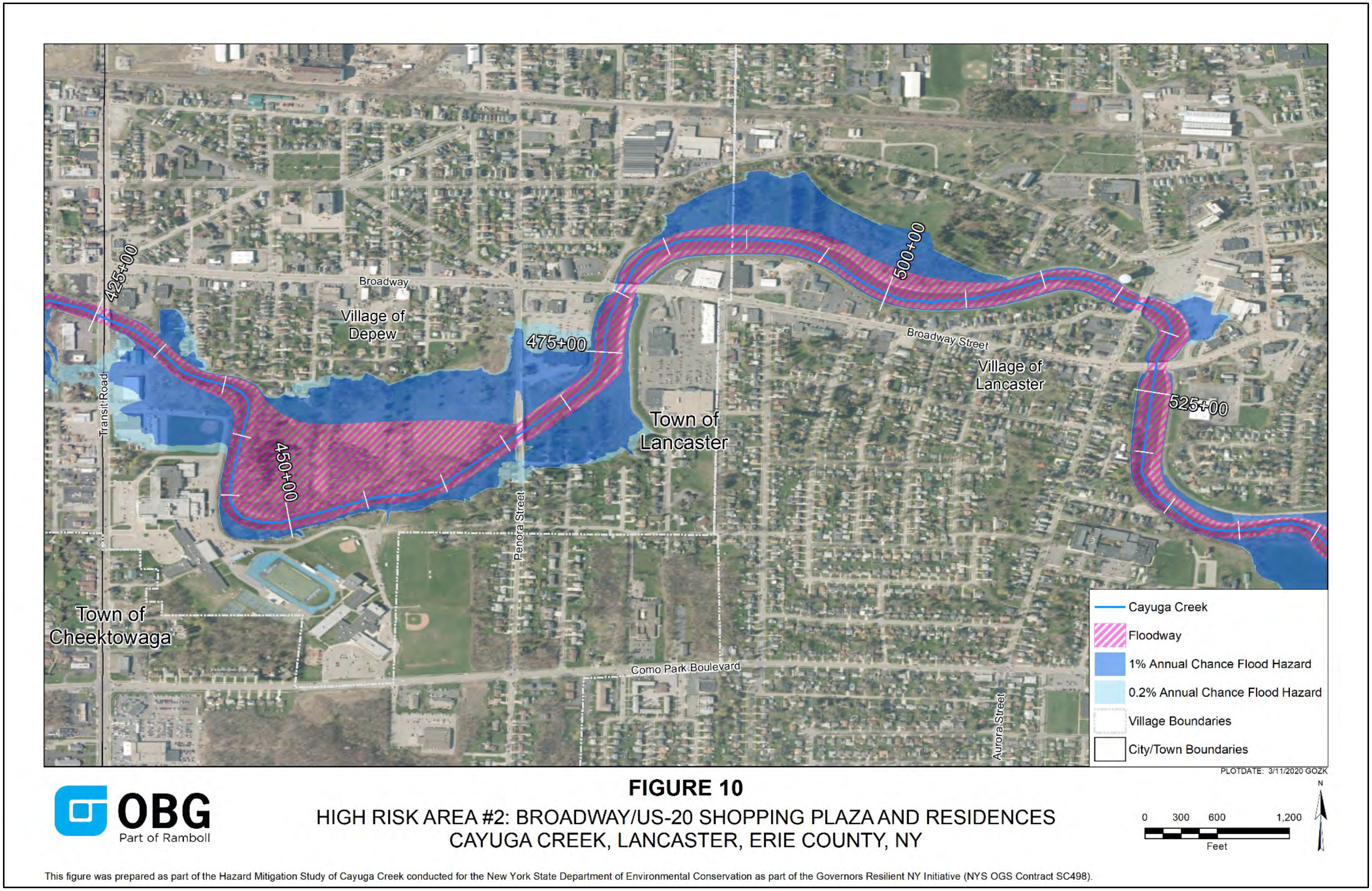

Figure 10. High Risk Area #2: Broadway/US-20 Shopping Plaza and Residence, Cayuga Creek, Lancaster, Erie County, NY.

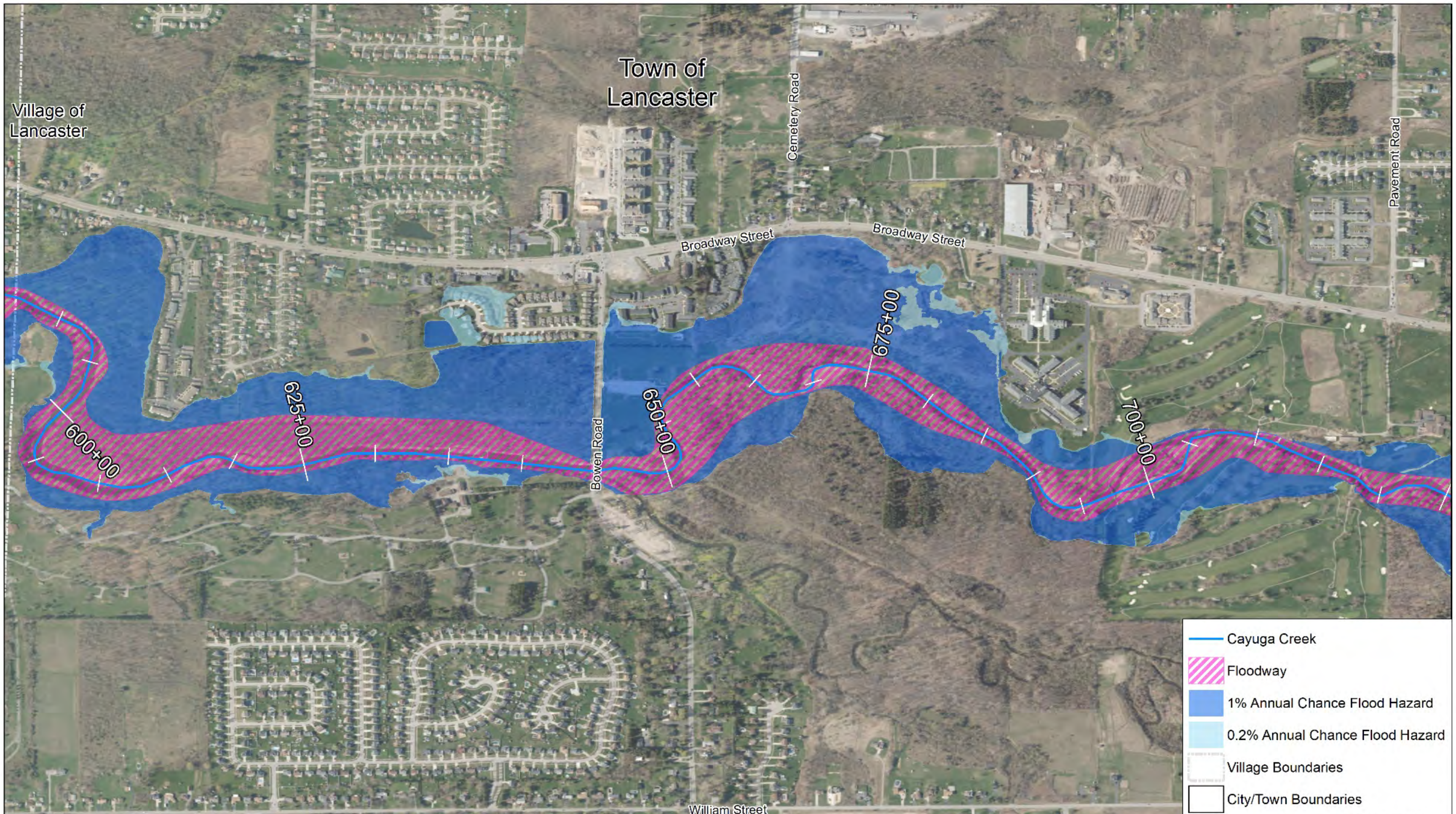

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FIGURE 11

HIGH RISK AREA #3: CONFLUENCE WITH LITTLE BUFFALO CREEK
CAYUGA CREEK, LANCASTER, ERIE COUNTY, NY

N

0 400 800 1,600
Feet

This figure was prepared as part of the Hazard Mitigation Study of Cayuga Creek conducted for the New York State Department of Environmental Conservation as part of the Governors Resilient NY Initiative (NYS OGS Contract SC498).

Figure 11. High Risk Area #3: Confluence with Little Buffalo River, Cayuga Creek, Lancaster, Erie County, NY.

MITIGATION RECOMMENDATIONS

HIGH RISK AREA #1

Alternative #1-1: Widen/Remove the Rowley Road Bridge

This measure is intended to address issues within High Risk Area #1 by widening the bridge opening 30-ft along Cayuga Creek, or removing the bridge and its associated piers, which would increase the cross-sectional area and in-channel flow of Cayuga Creek located at river station 283+46. According to the FEMA FIS and the base condition HEC-RAS model, the Rowley Road bridge is undersized causing backwater at annual-chance flood levels less than and equal to 10%, and does not allow the required 2-feet of freeboard over the 1% annual-chance flood water surface elevation. In addition, the close proximity of the Rowley Road bridge to the Como Park Boulevard bridge downstream and their associated embankments, have led to a narrowing of the creek channel and constricting of flow as it passes under the bridges. This constriction increases the potential for ice-jam formation and backwater flooding upstream of the Rowley Road bridge (Figure 12).

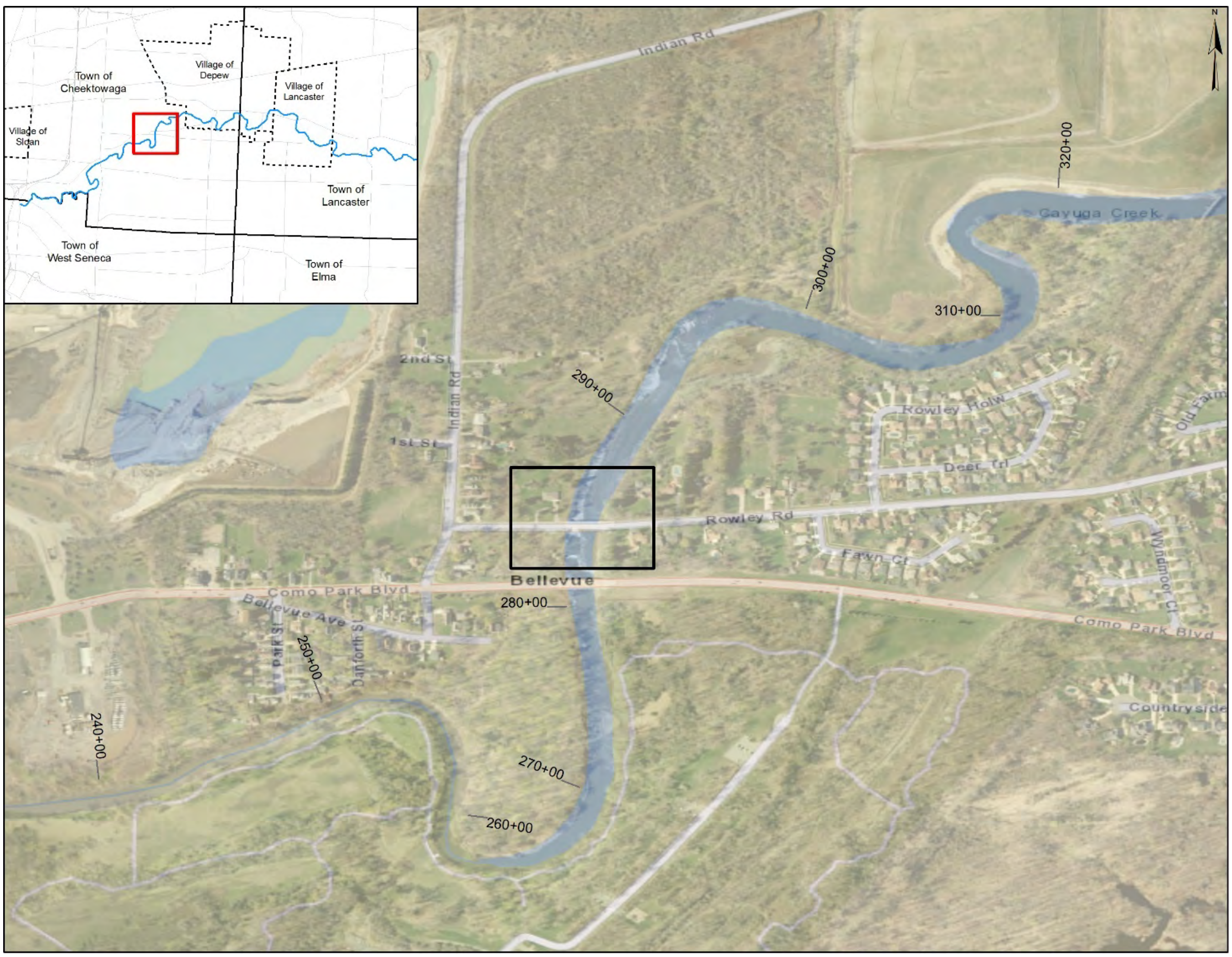

Figure 12. Alternative #1-1 location map.

The proposed condition modeling confirmed that the Rowley Road bridge is a constriction point along Cayuga Creek. The simulation output results indicate that the bridge and its piers restrict flow causing the water to contract and flow downstream under the bridge. At higher flows, this causes backwater and increased water surface elevations immediately upstream of the bridge. Water surface elevation reductions of up to 1-ft for a 1% annual-chance flood event were simulated while modeling widening the bridge opening by 30-ft. Water surface elevation reductions of up to 2.5-ft for a 1% annual-chance flood event were simulated while modeling removing the Rowley Road bridge (Figure 13). The future conditions modeling output displayed similar results with starting water surface elevations 0.1 to 0.8-feet higher. In both proposed condition model simulations, the backwater effect of the Rowley Road bridge is reduced, and water surface elevation reductions extend upstream 9,000-ft to the Borden Drive bridge.

To assess the influence of ice jams on the Rowley Road bridge and its piers, an ice cover simulation with a 1-ft ice thickness was performed. This simulation was intended to mimic the effects of an ice jam upstream of the bridge, which would reduce cross-sectional area and increase the in-channel roughness. When compared to existing conditions with ice cover, the simulation results indicated that for a 10-year flood event with approximately 9,510 cfs and a 1-foot thick ice cover, water surface elevations would be reduced by up to 0.5-ft for the bridge widening and up to 1-ft for the bridge removal simulations (Figure 14).

The Rowley Road bridge has two piers and an embankment on the right bank that narrows the creek channel. As a result, when surface ice forms in the creek upstream and travels downstream towards the bridge, the piers and embankment act as a barrier to, and restricts flow in the channel, increasing the potential for ice jam formation and flooding. Therefore, by widening the bridge opening or removing the bridge, its piers, and the concrete embankment, the potential for ice jamming and associated water level rises in the area can be reduced. Potential objections to widening the Rowley Road bridge include partial acquisition of adjacent private property, and traffic complications during construction. Potential objections to removing the bridge include traffic complication due to nearby residents being forced to find alternative routes. To mitigate objections, acquisition of open land approximate 1,900-ft east of the Rowley Road bridge for construction of an auxiliary roadway to connect Rowley Road and Como Park Boulevard should be considered.

The potential water surface elevation reduction benefits of this alternative would extend upstream of the Rowley Road bridge, specifically along river stations 280+00 to 370+00.

The Rough Order Magnitude cost for these measures are $750,000 to remove the bridge or $4.7 Million to widen the Rowley Road bridge, not including land acquisition costs for survey, appraisal, and engineering coordination for the bridge widening.

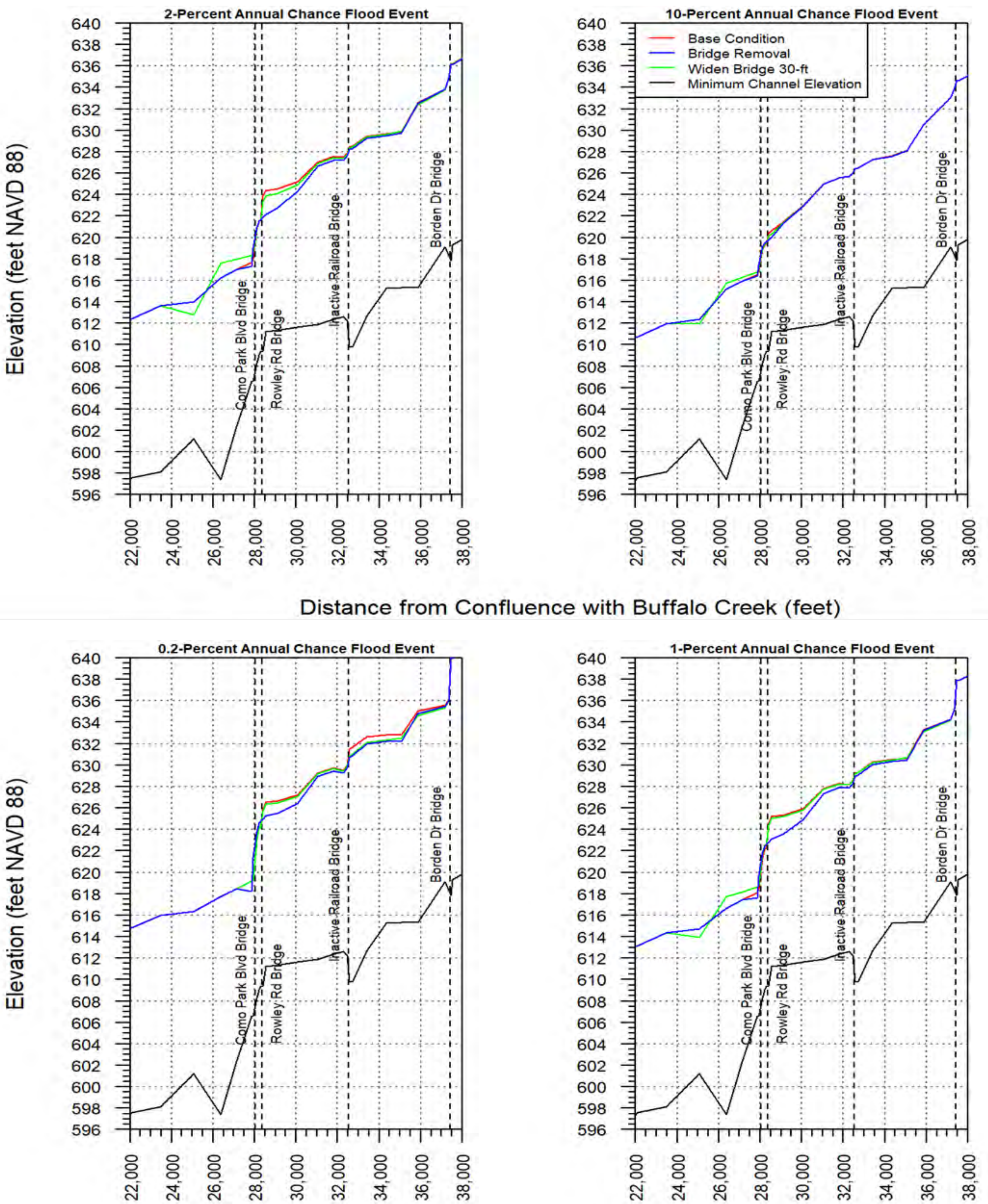

Figure 13. HEC-RAS proposed condition model simulation results for alternative #1-1.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the Rowley Road bridge removal (blue), bridge widening by 30-ft (green), and base condition (red) model simulation results.

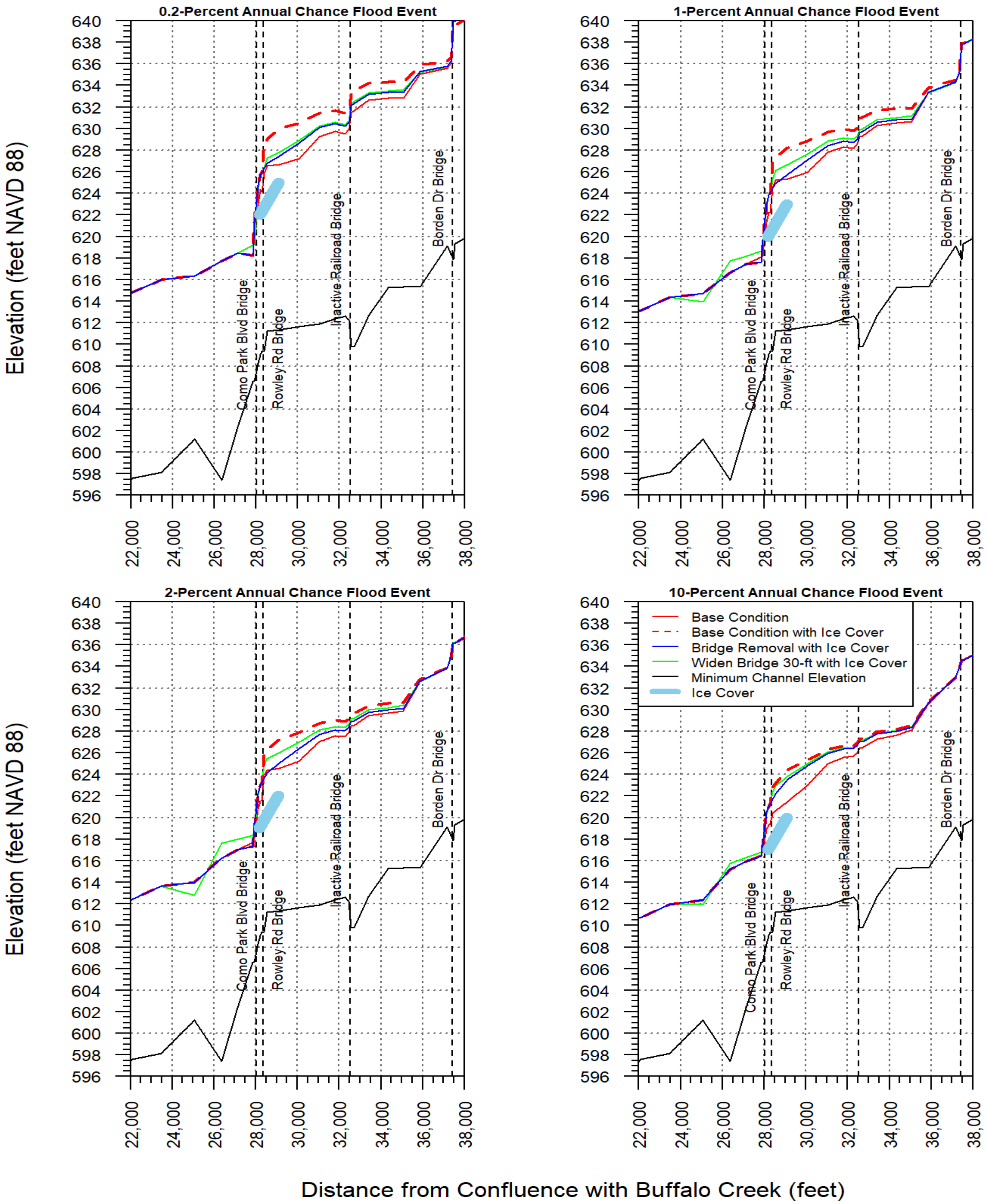

Figure 14. HEC-RAS ice cover model simulation results for alternative #1-1.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the Rowley Road bridge removal with ice cover (blue), widening the bridge opening by 30-ft with ice cover (green), base condition with ice cover (red dashed), and base condition (red) model simulation results.

Alternative #1-2: Remove Inactive Railroad Bridge

This measure is intended to address issues within High Risk Area #1 by removing the inactive railroad bridge adjacent to the old Village of Depew Division of Public Works landfill, which would increase the in-channel flow area, located at river station 325+31. The landfill is owned by Schultz Landfill, Inc. According to the FEMA FIS and the base condition HEC-RAS model, the railroad bridge is undersized, causing backwater at annual-chance flood levels less than and equal to 10%, and does not allow the required 2-feet of freeboard over the 1% annual-chance flood water surface elevation. Removing the railroad bridge and associated pier that supports the bridge would remove in-channel impediments to the flow of water, sediment, debris, and ice. Removal of this impediment would reduce flow constriction at the railroad bridge, which has historically caused ice-jam floods in this area, and address issues within High Risk Area #1 (Figure 15).

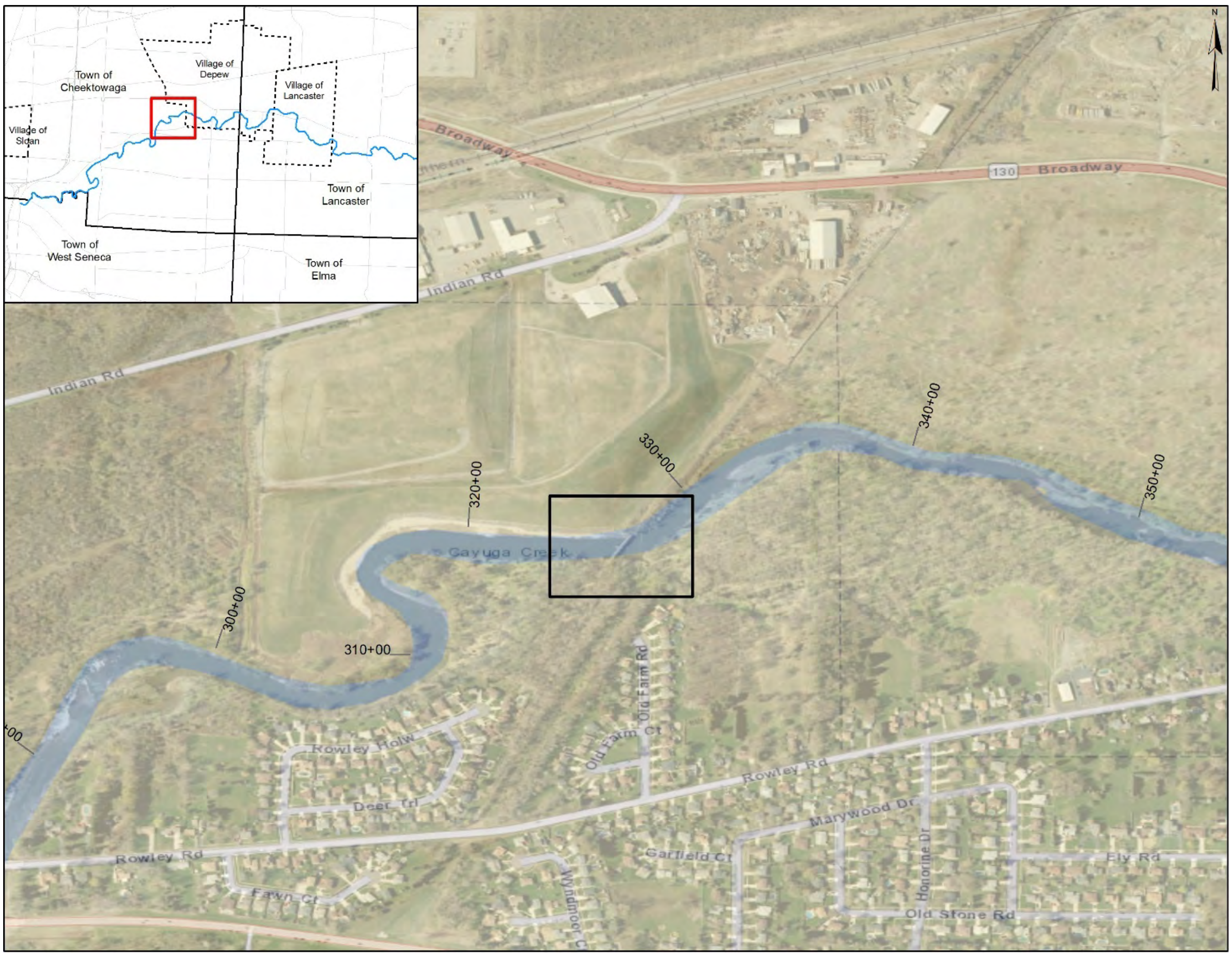

Figure 15. Alternative #1-2 location map.

The proposed condition modeling confirmed that the inactive railroad bridge and its features is a constriction point along Cayuga Creek. Removal of the railroad bridge resulted in a reduction in water surface elevations downstream of the railroad bridge of approximately 0.8-feet (Figure 16). In the future condition model simulation, removing the railroad bridge reduced water surface elevations by approximately 0.8-feet. The railroad removal simulation output results indicate that the railroad bridge has a minor influence on open-water surface elevations in this section of Cayuga Creek.

To assess the influence of ice jams on the railroad bridge and its pier, an ice cover simulation with 1-ft ice thickness was performed. This simulation was intended to mimic the effects of an ice jam upstream of the railroad bridge, which would reduce cross-sectional area and increase the in-channel roughness. When compared to existing conditions with ice cover, the simulation results indicated that for a 10-year flood event with approximately 9,510 cfs and a 1-ft thick ice cover, water surface elevations would be reduced by up to 1-ft for the bridge removal simulations (Figure 17). The backwater impacts of an ice jam at the railroad bridge was also simulated to extend upstream 5,000-ft to the Borden Road bridge.

By removing the railroad bridge piers, the potential for ice jamming and associated water level rises in the area can be reduced, particularly during higher flow events. Both our analysis and FEMA Flood Insurance Study are based on open water, non-jam events. A jam of any nature will reduce the effective opening of the bridge, resulting in significant backwater. Therefore, the removal of the abandoned railroad bridge reduces or eliminates the potential occurrences of jams in this area, which will reduce the potential for backwater flooding.

The Rough Order Magnitude cost for this measure is $210,000.

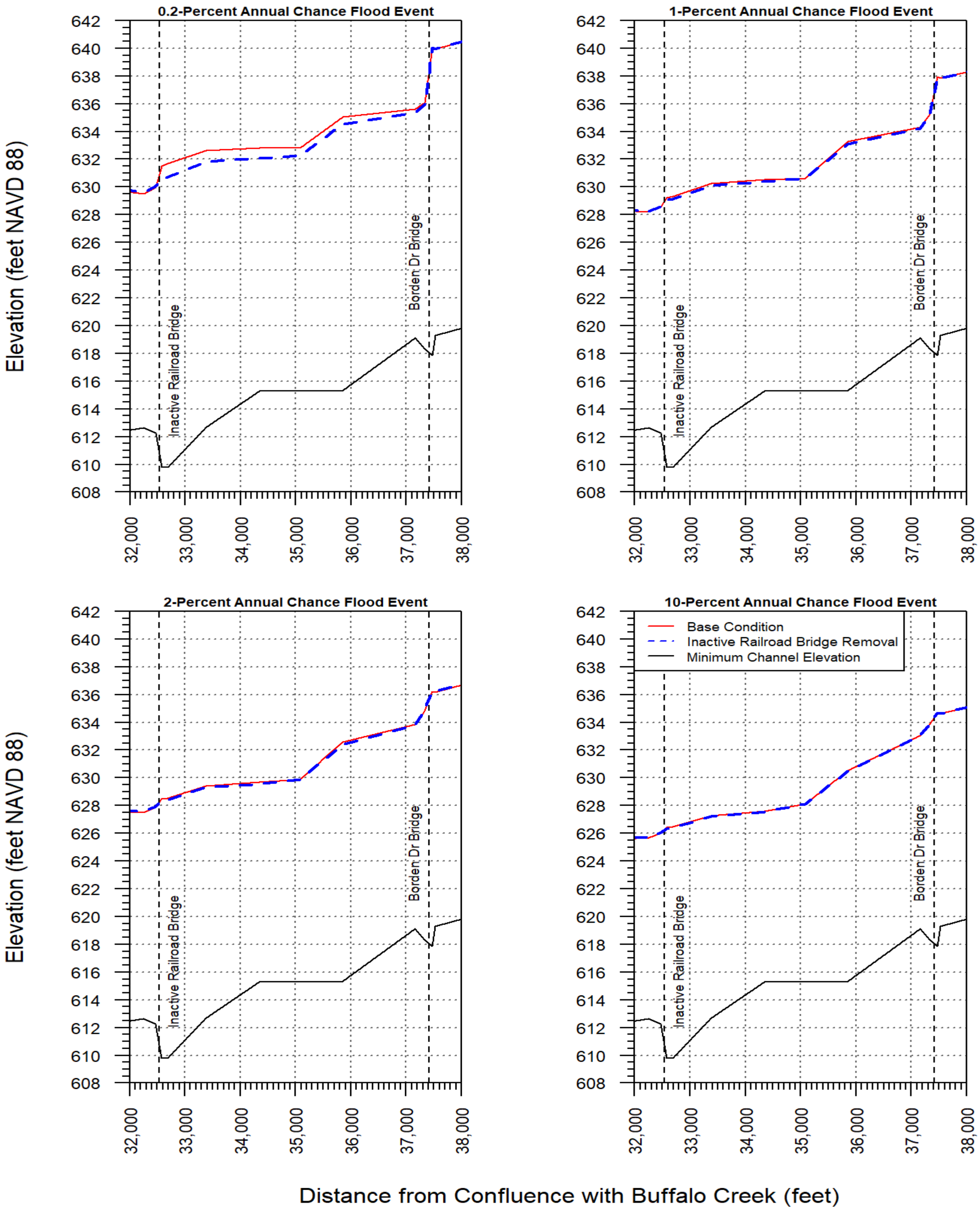

Figure 16. HEC-RAS proposed condition model simulation results for alternative #1-2.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the Inactive Railroad bridge removal (blue) and base condition (red) model simulation results.

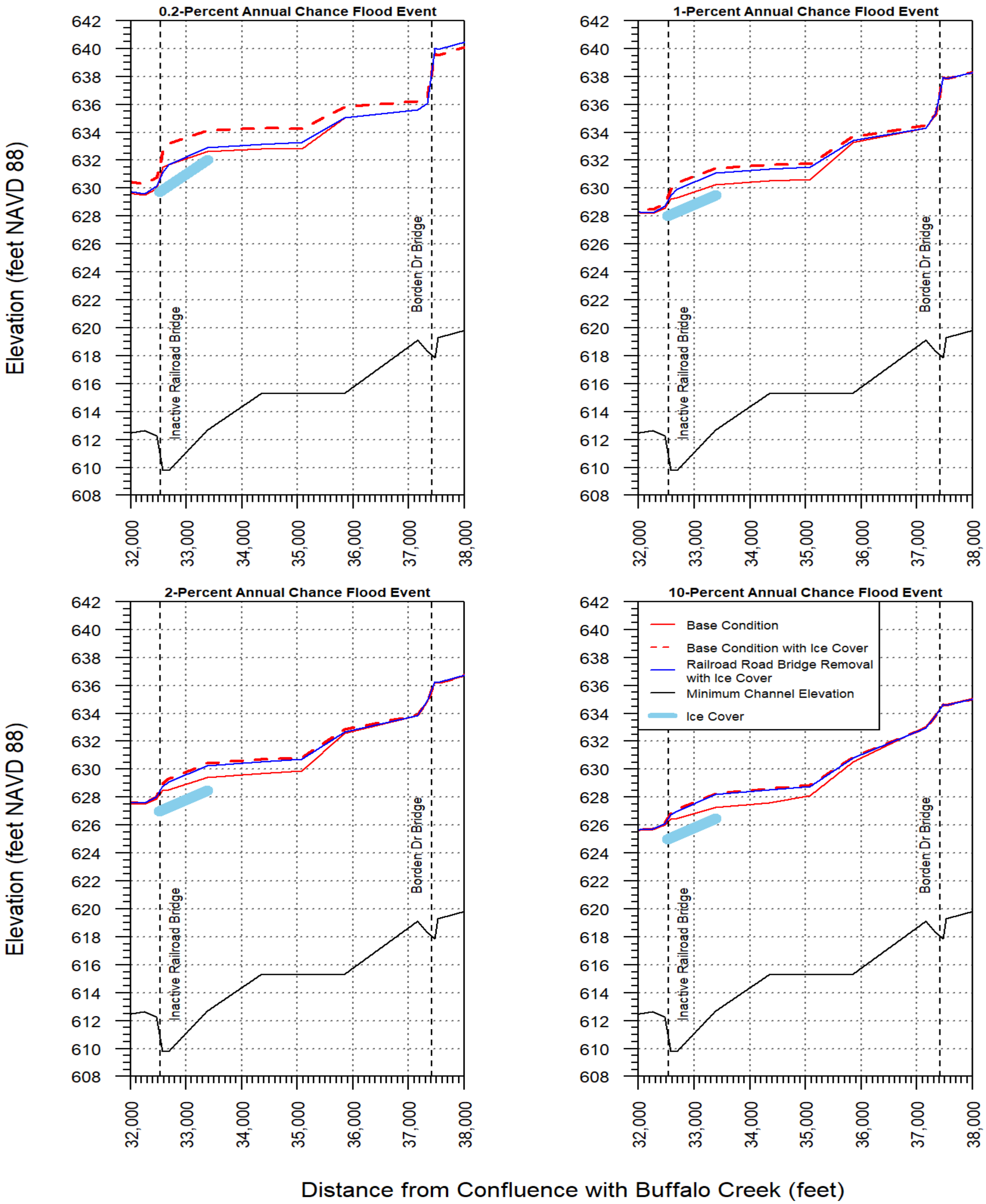

Figure 17. HEC-RAS ice cover model simulation results for alternative #1-2.

Note: The 10, 2, 1, 0.2% annual-chance flood event water surface elevations (ft) for the inactive railroad bridge removal with ice cover (blue), base condition with ice cover (red dashed), and base condition (red) model simulation results.

Alternative #1-3: Install Flood Bench in Vicinity of Inactive Railroad Bridge

Installing a flood bench would provide additional storage and floodplain width, which could potentially reduce damages in the event of flooding and address issues within High Risk Area #1. Three different flood benches were modeled at various locations both upstream and downstream of the inactive railroad bridge. The total acreage of the flood benches varied from 3.6 to 20 acres. All three flood benches are located on the left bank of Cayuga Creek and are 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 (Figure 18).

Bench A is located upstream of the Rowley Road bridge between river stations 287+00 and 310+00, and would require the excavation of 3.6 acres of land. Bench B is located downstream of the inactive railroad bridge between river stations 308+50 and 322+50, and would require the excavation of 5.6 acres of land. Bench C is located upstream of the inactive railroad bridge between river stations 325+00 and 351+00, and would require the excavation of 20.0 acres of land. In addition, a fourth scenario was investigated to determine if clearing the left bank of large trees and vegetation along Bench C would produce any water surface elevation reductions. This scenario was simulated by reducing the Manning's n value coefficients in the overbank areas that intersected Bench C in the HEC-RAS model.

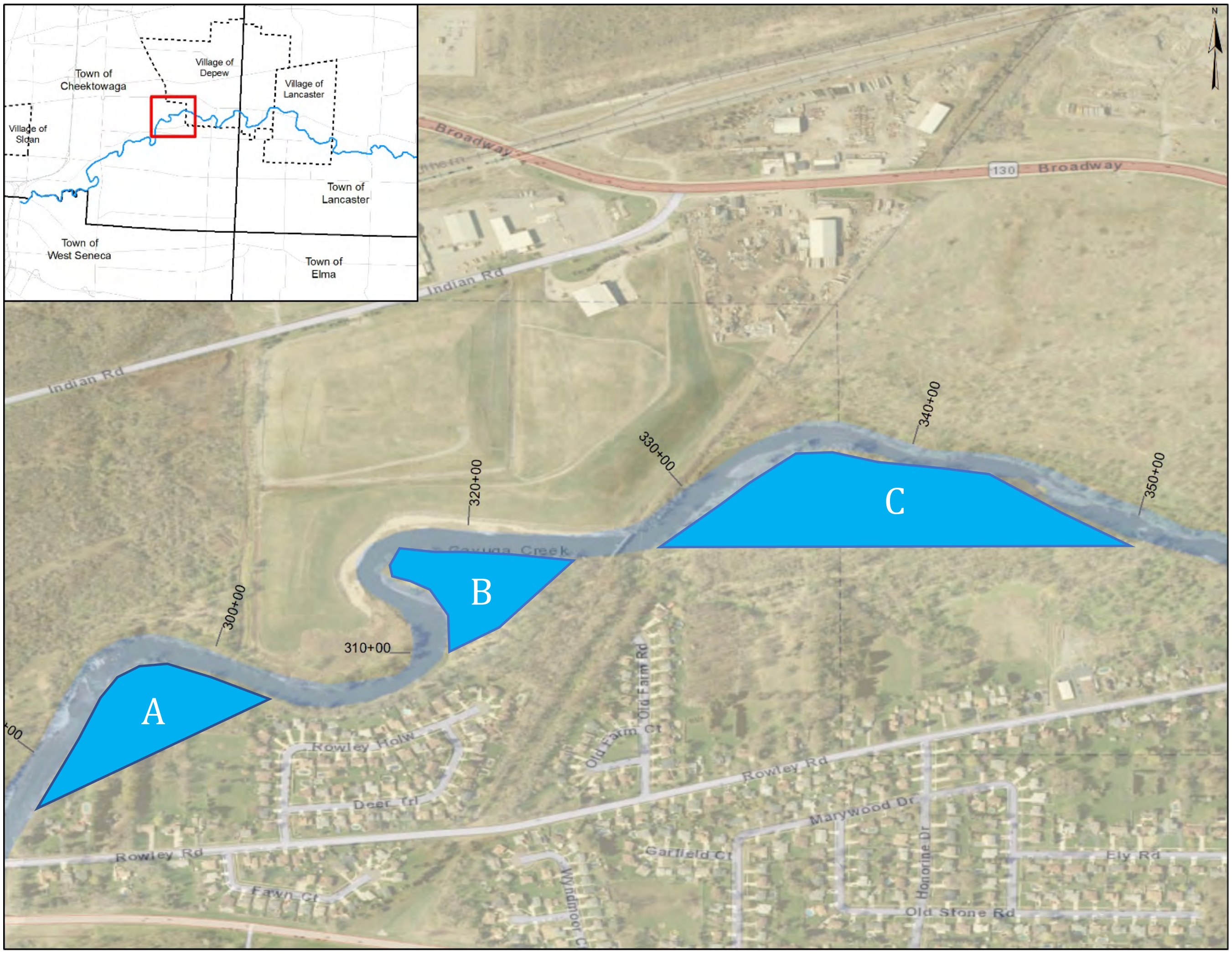

Figure 18. Alternative #1-3 location map.

The proposed condition modeling confirmed that the inactive railroad bridge and its features are a constriction point along Cayuga Creek. In the proposed condition simulation, three flood benches of varying acreage were modeled to determine the location and size of the best performing flood bench in this area. Each flood bench simulated a reduction in water surface elevation with a range of approximately 0.4 to 1.0-ft according to the model output. Additionally, clearing the left bank of large trees and vegetation was modeled by reducing the Manning's roughness coefficient in the overbank area on the left bank of Cayuga Creek for the cross sections in the vicinity of the flood bench, and results indicated a potential water surface elevation reduction of up to 0.6-ft (Figures 19, 21, 23, and 25). The modeling output for future conditions displayed similar results with water surface elevations up to 0.8-ft higher due to the increased discharges associated with predicted future flows in Cayuga Creek. Table 8 is a summary of the simulations and results with river stationing, acreage, and maximum water surface elevation reductions according to model simulation results.

Table 8. Summary of Alternative #1 3 Simulations and Results			
Simulation ID	**River Station**	**Acreage (ac)**	**Maximum Water Surface Reduction (ft)**
Bench A	287+00 to 310+00	3.6	Up to 1.0-ft
Bench B	308+50 to 322+50	5.6	Up to 0.8-ft
Bench C	325+00 to 351+00	20.0	Up to 0.4-ft
Scenario D	325+00 to 351+00	Reduced Manning's n Values	Up to 0.6-ft

To assess the influence of ice jams in the vicinity of the inactive railroad bridge, an ice cover simulation with 1-foot ice thickness was performed for each flood bench and Scenario D. The simulations were intended to mimic the effects of an ice jam upstream and in the vicinity of the railroad bridge, which would reduce cross-sectional area and increase the in-channel roughness. When compared to existing conditions with ice cover, the simulation results indicated that for a 10-year flood event with approximately 9,510 cfs and a 1-foot thick ice cover, water surface elevations would be reduced by up to 0.7-ft for Bench A, up to 0.5-ft for Bench B, up to 1.0-ft for Bench C, and up to 0.6-ft for Scenario D (Figures 20, 22, 24 and 26).

By incorporating a flood bench, the potential for backwater flooding caused by ice jamming at the Rowley Road bridge and inactive railroad bridge can be reduced. The potential benefits of this strategy are limited to the areas in the vicinity of each flood bench, specifically at the location of each flood bench upstream to the Borden Drive bridge at river station 374+08.

The Rough Order Magnitude cost for Bench A is $1.6 Million, Bench B is $2.2 Million, Bench C is $4.8 Million, and Scenario D is $185,000, not including land acquisition costs for survey, appraisal, and engineering coordination.

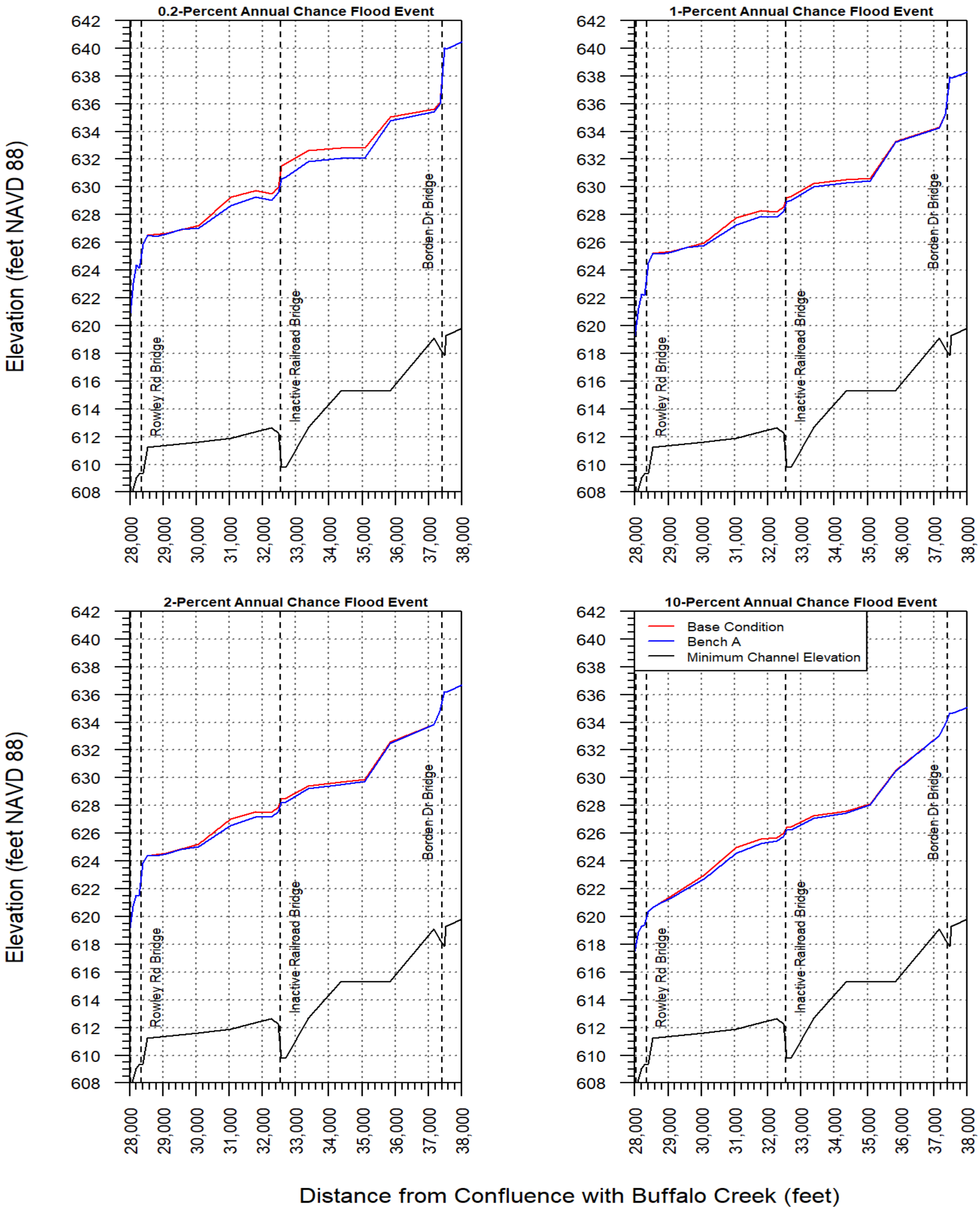

Figure 19. HEC-RAS proposed condition model simulation results for alternative #1-3 Bench A.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the flood bench (blue) and base condition (red) model simulation results.

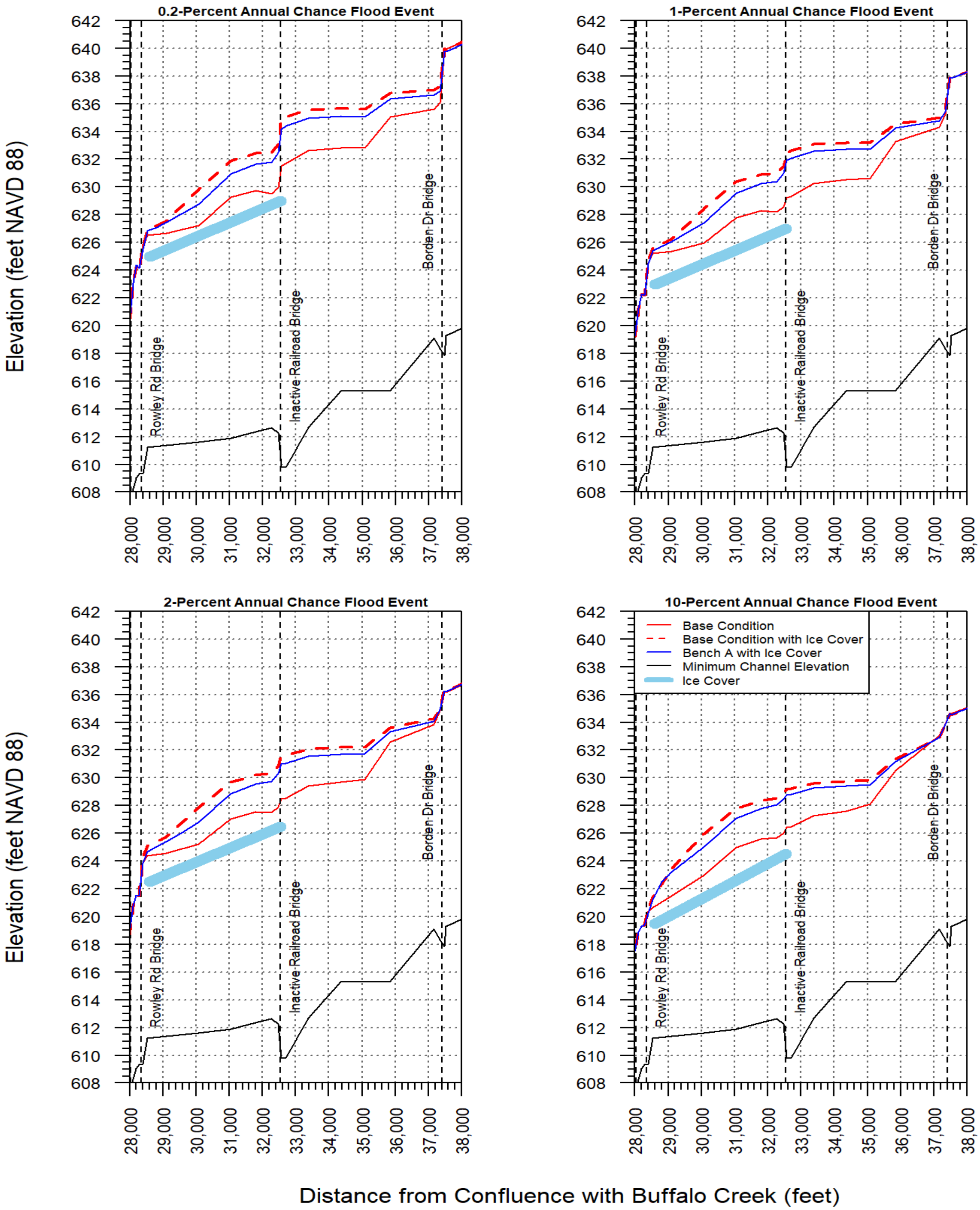

Figure 20. HEC-RAS ice cover model simulation results for alternative #1-3 Bench A.

Note: The 10, 2, 1, 0.2% annual-chance flood event water surface elevations (ft) for the flood bench with ice cover (blue), base condition with ice cover (red dashed), and base condition (red) model simulation results.

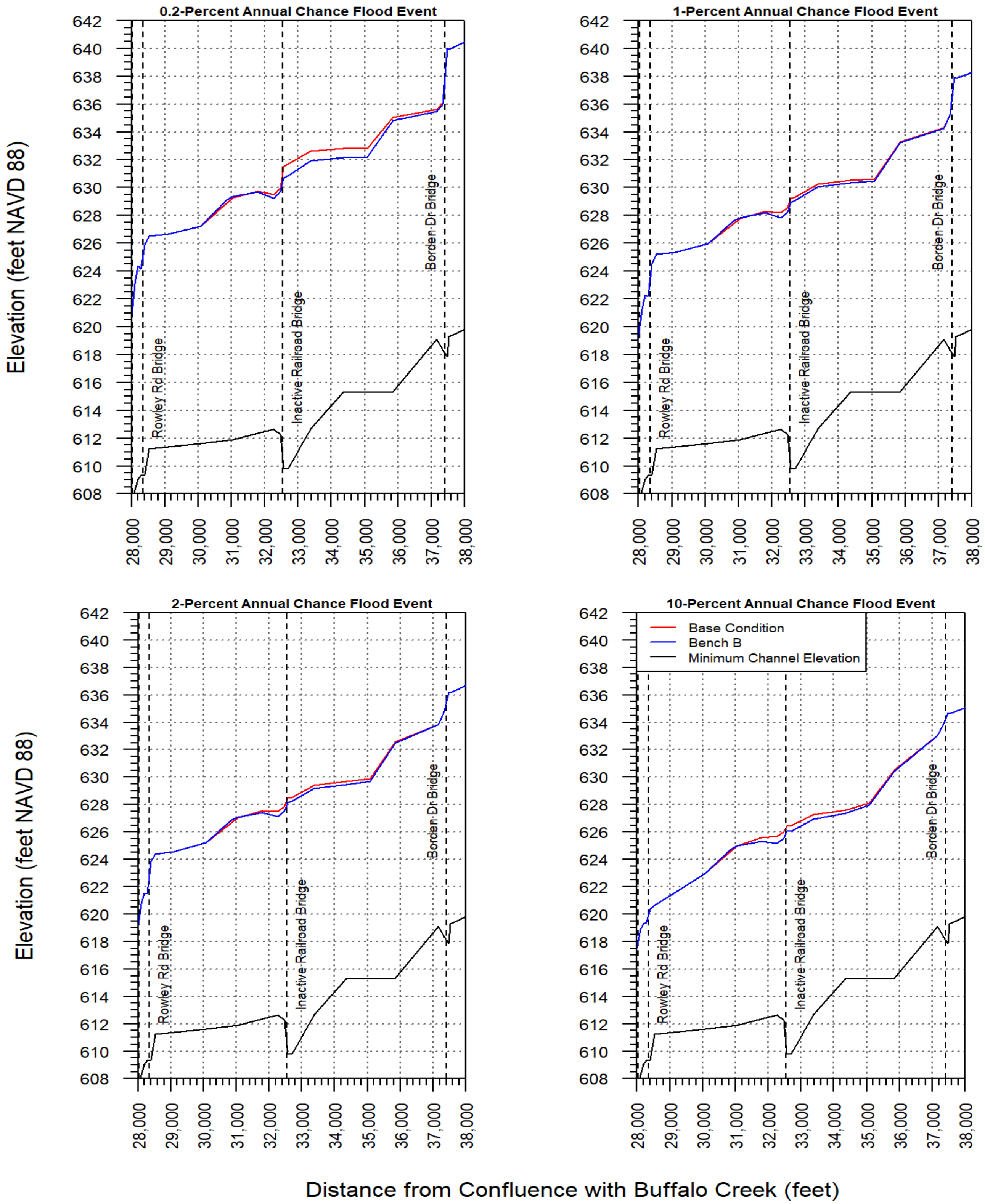

Figure 21. HEC-RAS proposed condition model simulation results for alternative #1-3 Bench B.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the flood bench (blue) and base condition (red) model simulation results.

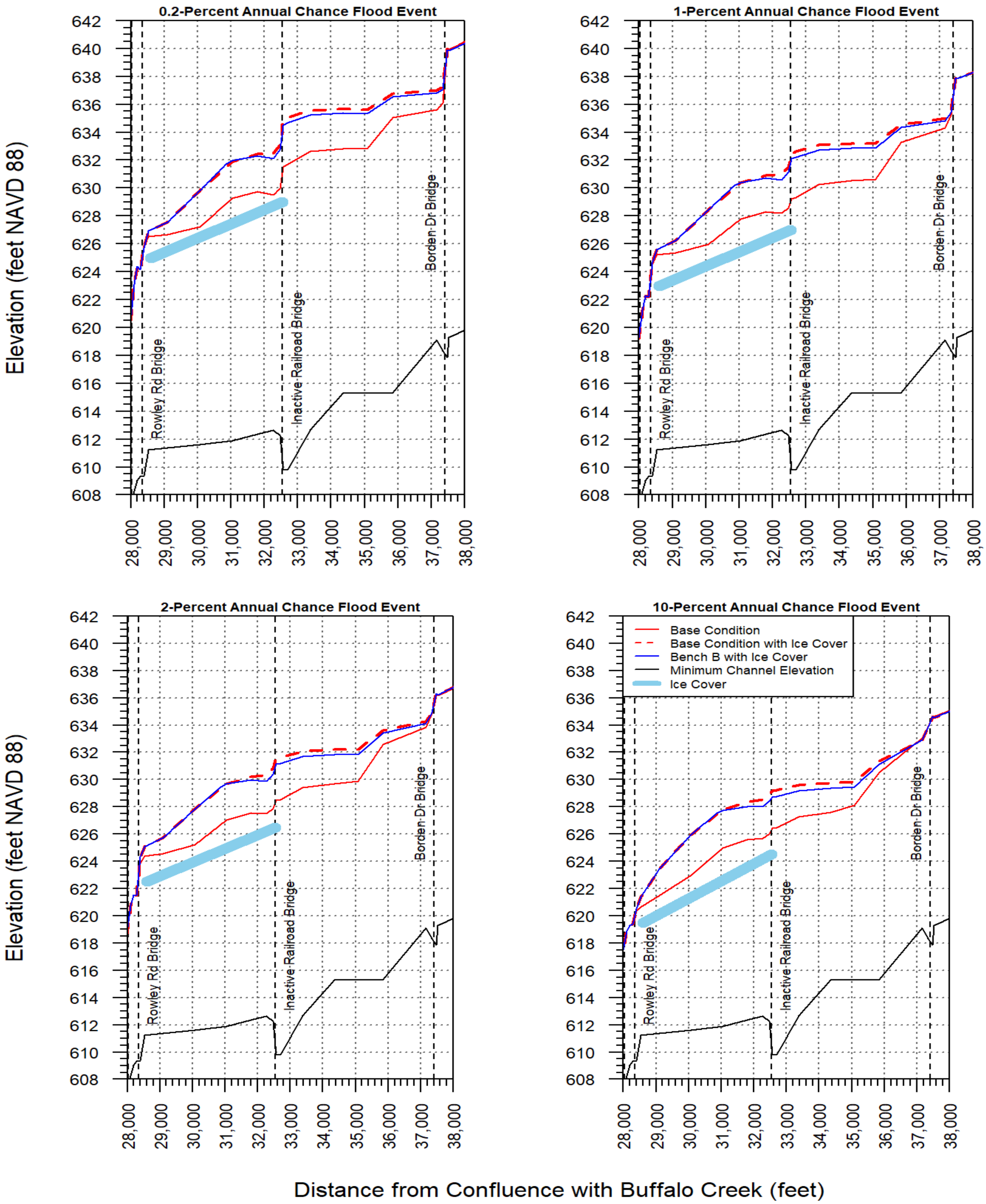

Figure 22. HEC-RAS ice cover model simulation results for alternative #1-3 Bench B.

Note: The 10, 2, 1, 0.2% annual-chance flood event water surface elevations (ft) for the flood bench with ice cover (blue), base condition with ice cover (red dashed), and base condition (red) model simulation results.

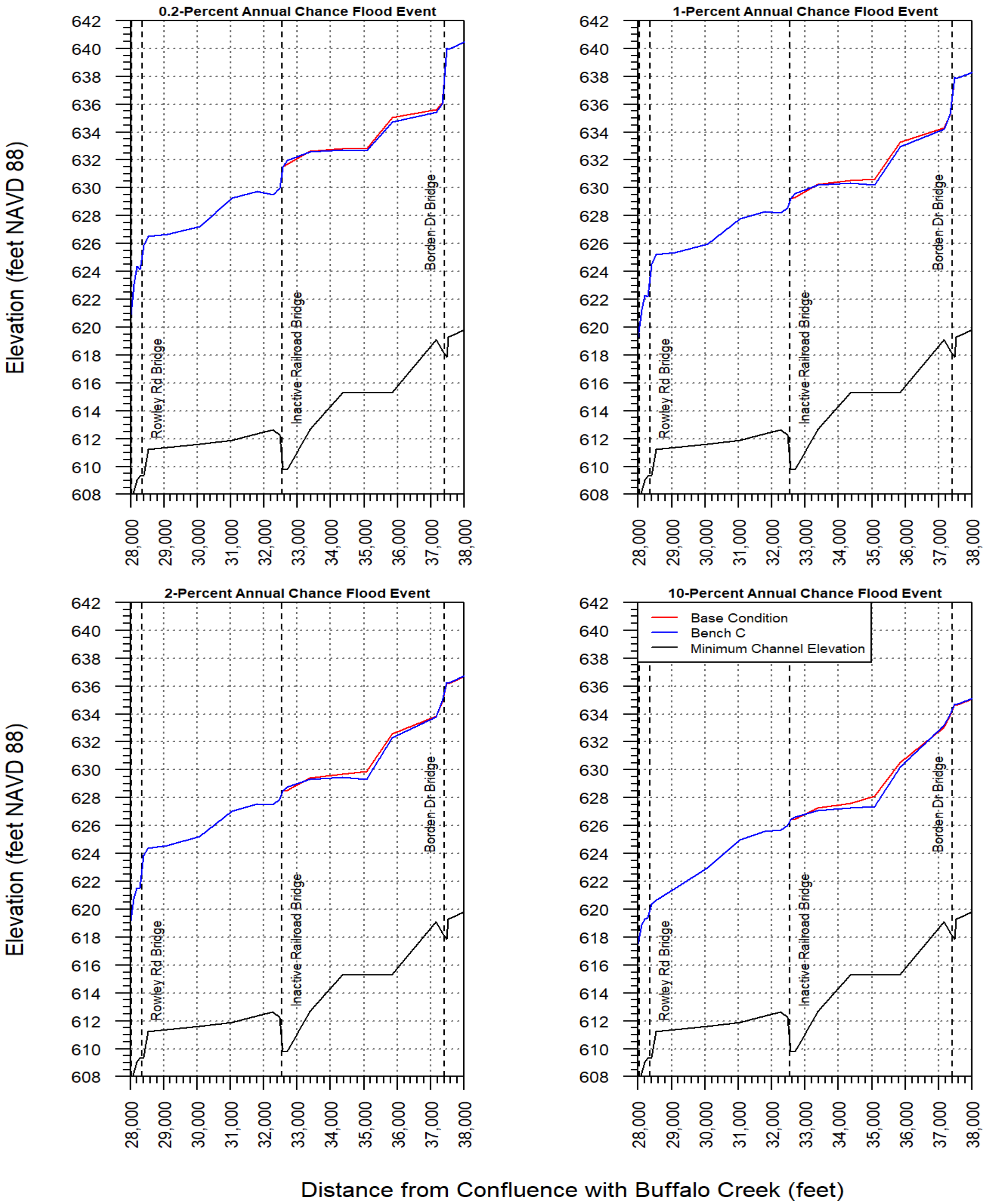

Figure 23. HEC-RAS proposed condition model simulation results for alternative #1-3 Bench C.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the flood bench (blue) and base condition (red) model simulation results.

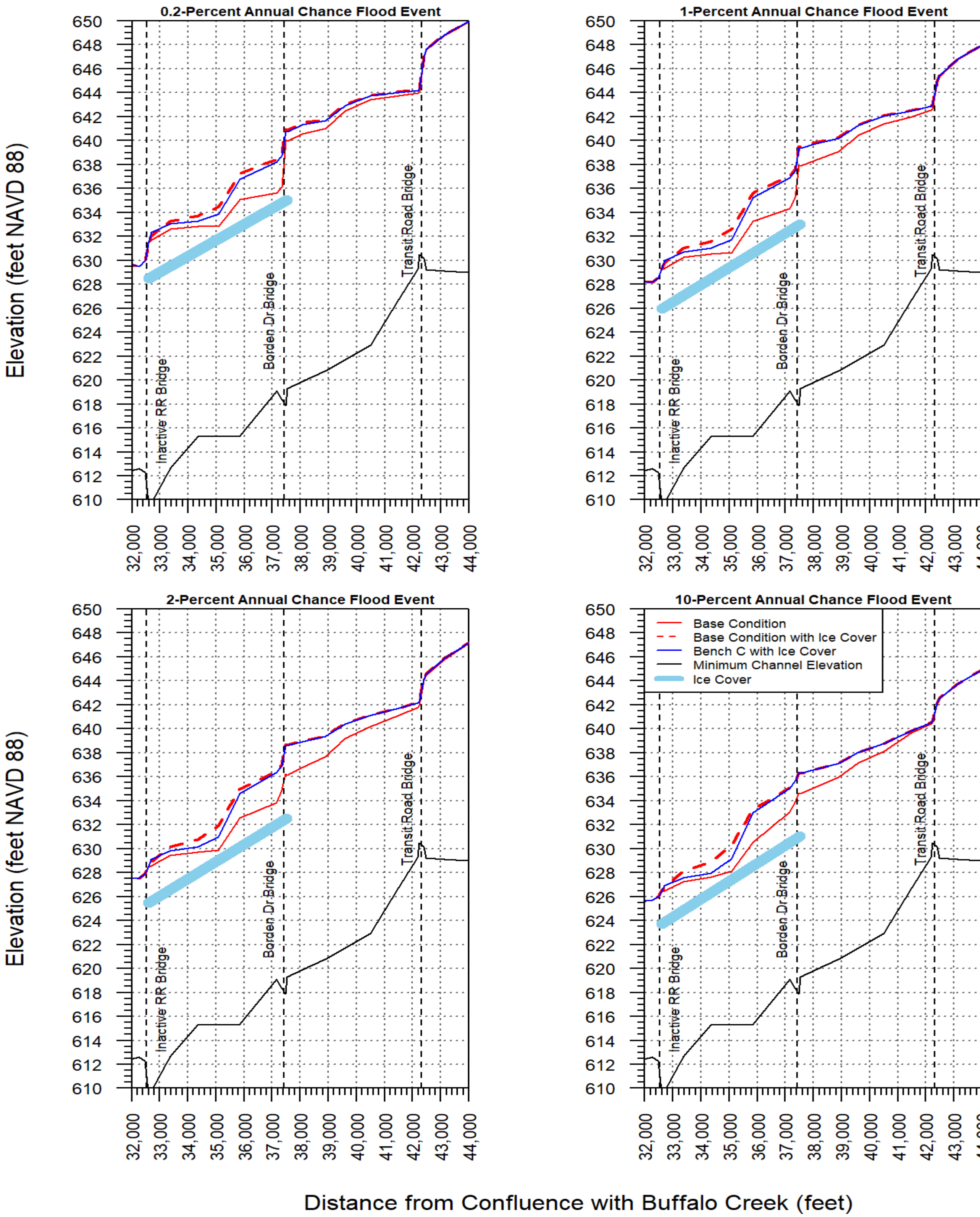

Figure 24. HEC-RAS ice cover model simulation results for alternative #1-3 Bench C.

Note: The 10, 2, 1, 0.2% annual-chance flood event water surface elevations (ft) for the flood bench with ice cover (blue), base condition with ice cover (red dashed), and base condition (red) model simulation results.

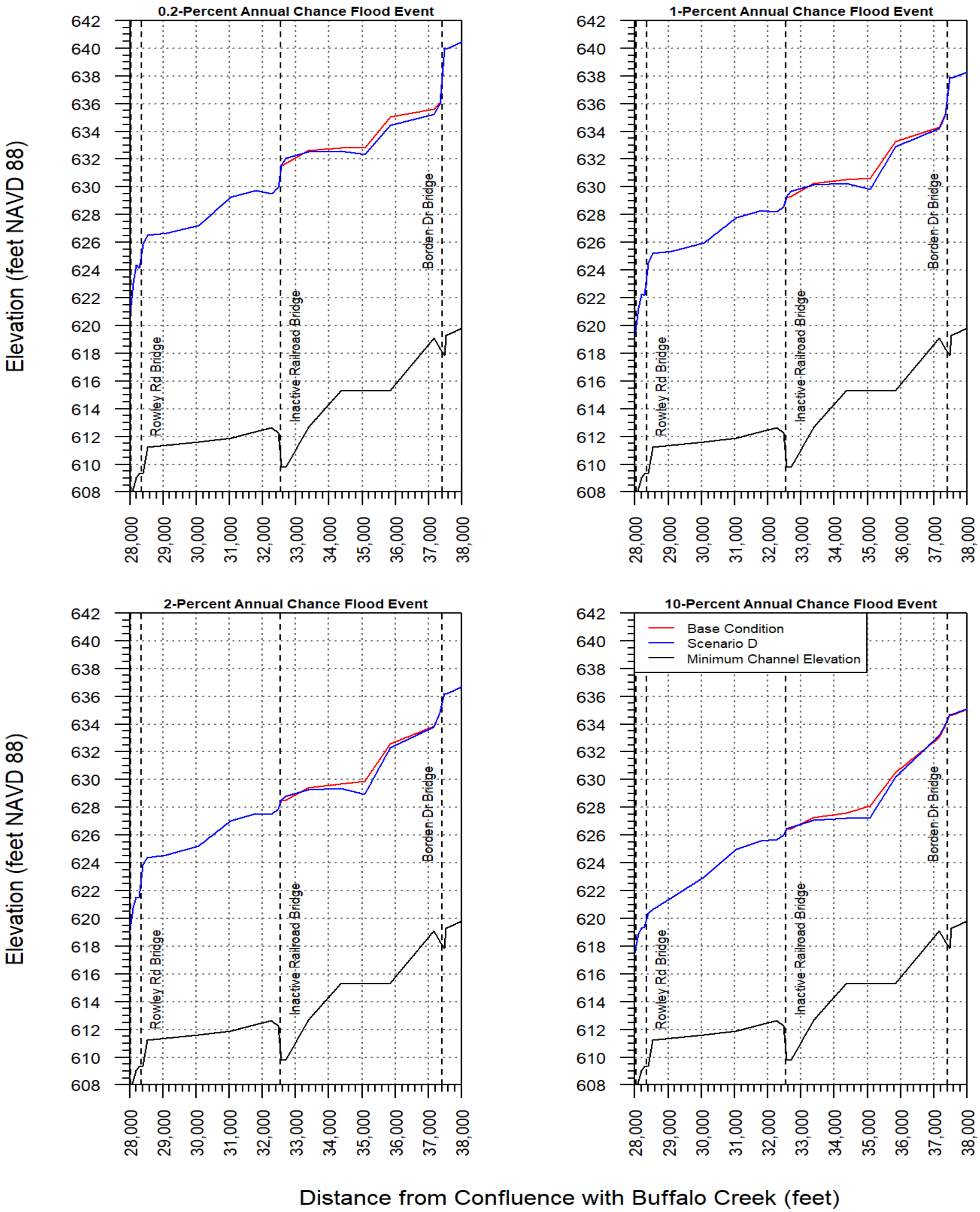

Figure 25. HEC-RAS proposed condition model simulation results for alternative #1-3 Scenario D.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the flood bench (blue) and base condition (red) model simulation results.

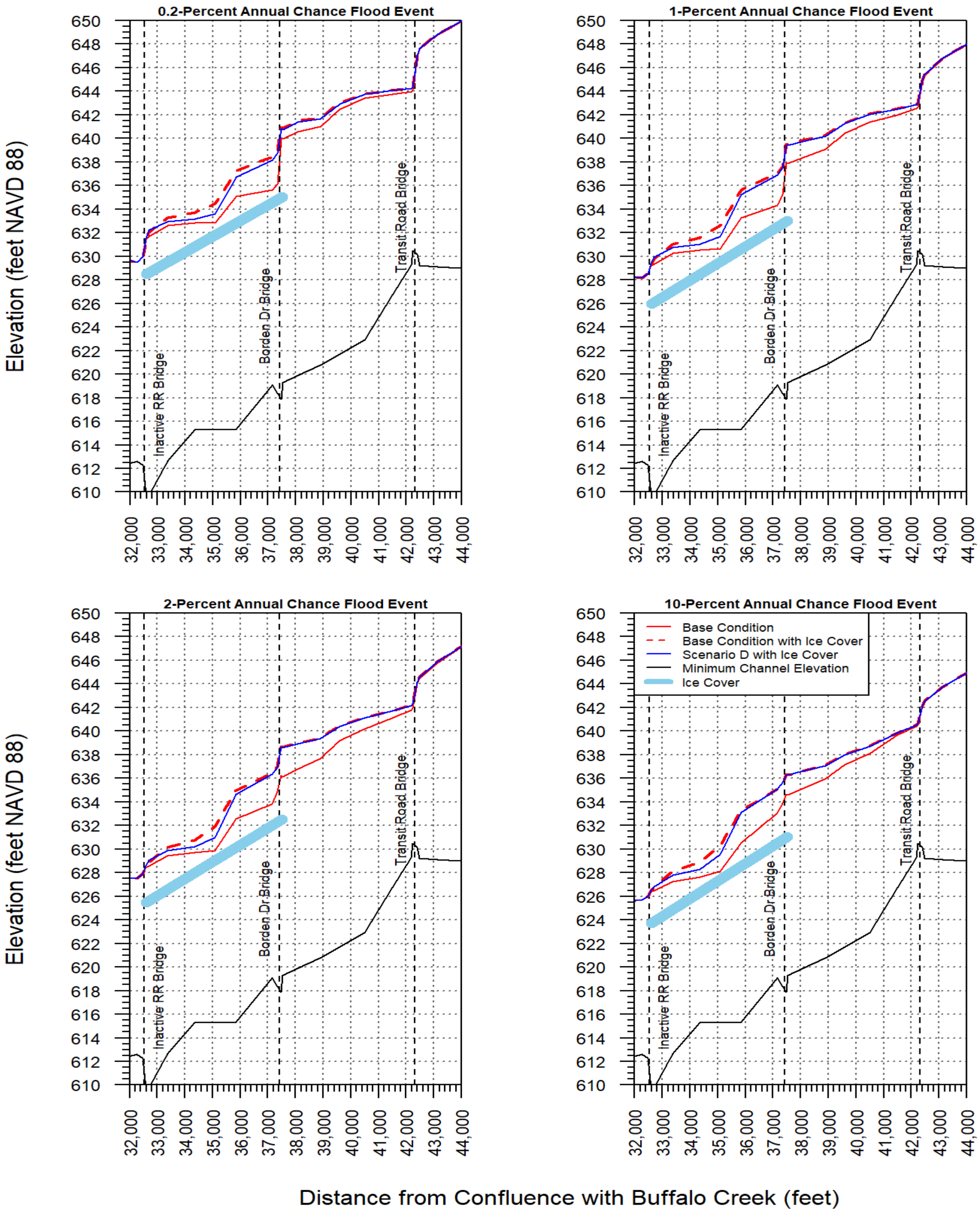

Figure 26. HEC-RAS ice cover model simulation results for alternative #1-3 Scenario D.

Note: The 10, 2, 1, 0.2% annual-chance flood event water surface elevations (ft) for the flood bench with ice cover (blue), base condition with ice cover (red dashed), and base condition (red) model simulation results.

Alternative #1-4: Ice Control Structure – Inactive Railroad Bridge

This strategy would need to be employed in conjunction with a flood bench project in order to provide the necessary storage area for ice collection and backwater caused by ice jamming. Ice control structures are constructed within the stream channel at a sufficient height where ice is captured within the channel. Water is then able to flow around the structures and captured ice (Lever et al. 2000). The structures direct the ice towards the flood bench which provides the required area to accommodate increased river stage during an ice jam event. The flood bench would be located in the vicinity of the high-risk area downstream of the inactive railroad bridge between river stations 308+50 to 322+50. Figure 27 depicts the most optimal location for an ice control structure and flood bench downstream of the inactive railroad bridge.

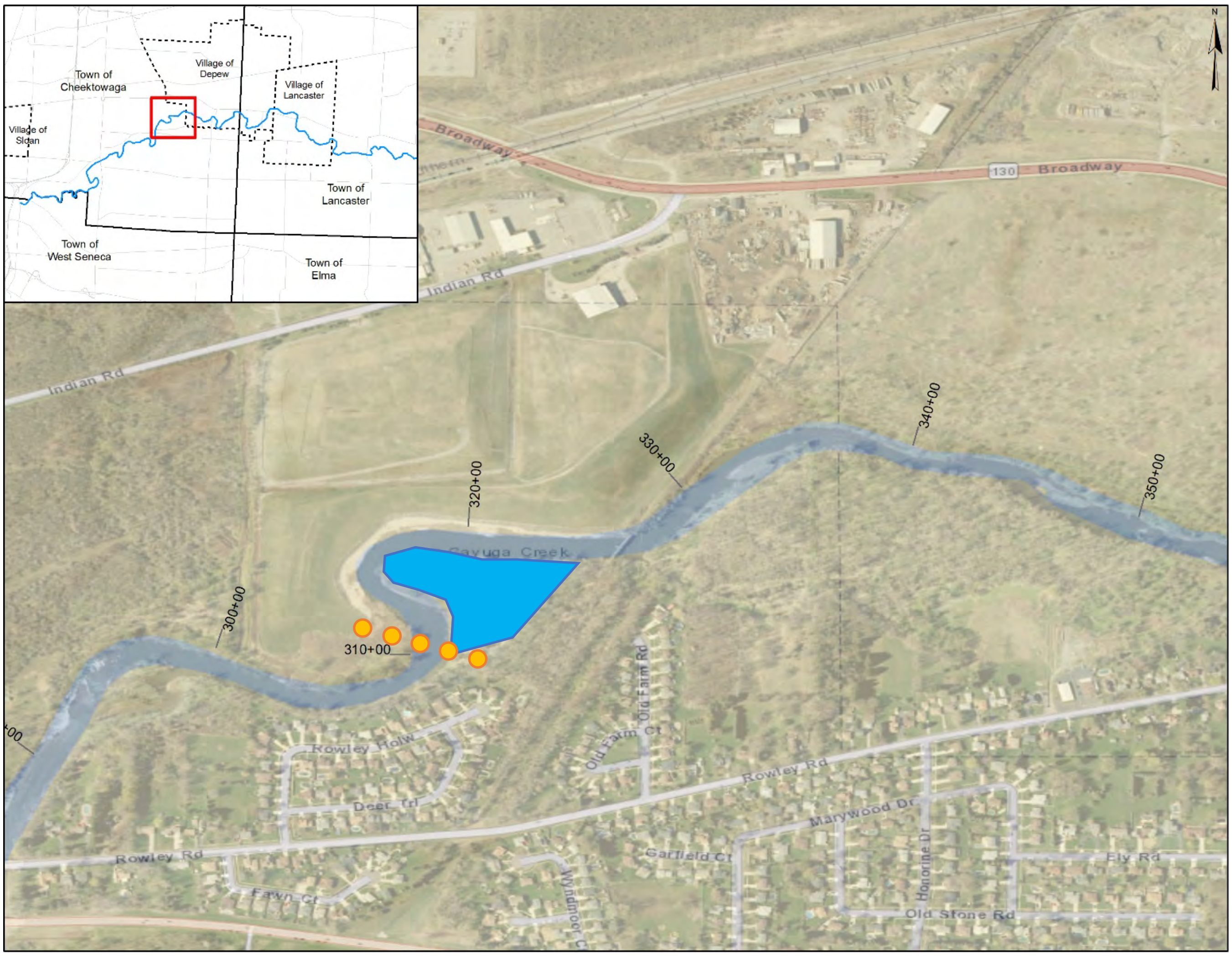

Figure 27. Alternative #1-4 location map.

Due to the complexity of freeze-up ice jam modeling and the limited scope of this study, hydraulic modeling was not performed to assess the impact of this strategy. The frazil ice and surface ice formation, and their dynamics with the hydraulics are complicated due to the number of variables that are needed to model these scenarios (variables such as water depths, surface area, air temperature, water temperature, turbulent condition and flow velocity, etc.). Therefore, any suggested ice control structures or ice control structures with flood benches in Cayuga Creek, would need to go through a dynamic ice freeze-up and break-up computer modeling (2D River Ice Dynamic Simulation) simulation to understand the ice transport and ice generation mechanism with, and without the structures to support the proposed design. Poorly designed structures may result in worsening the flooding potential, and unexpected scour can impact the existing banks and infrastructure, instead of mitigating the ice-jam related flooding.

The Rough Order Magnitude cost for an ice control structure downstream of the inactive railroad bridge would be approximately $7 Million, which includes construction of the flood bench and removal of the railroad bridge, but does not include land acquisition costs for survey, appraisal, and engineering coordination.

Alternative #1-5: Streambank Stabilization – Village of Depew Old DPW Landfill

This measure is intended to address issues within High Risk Area #1 by protecting the banks of Cayuga Creek from erosion and maintaining the flow capacity of the creek in the reach located between river stations 337+00 and 356+00 (Figure 28). This area has been subjected to bank degradation due to the meanders in the creek path that have caused sediment deposition and bank erosion.

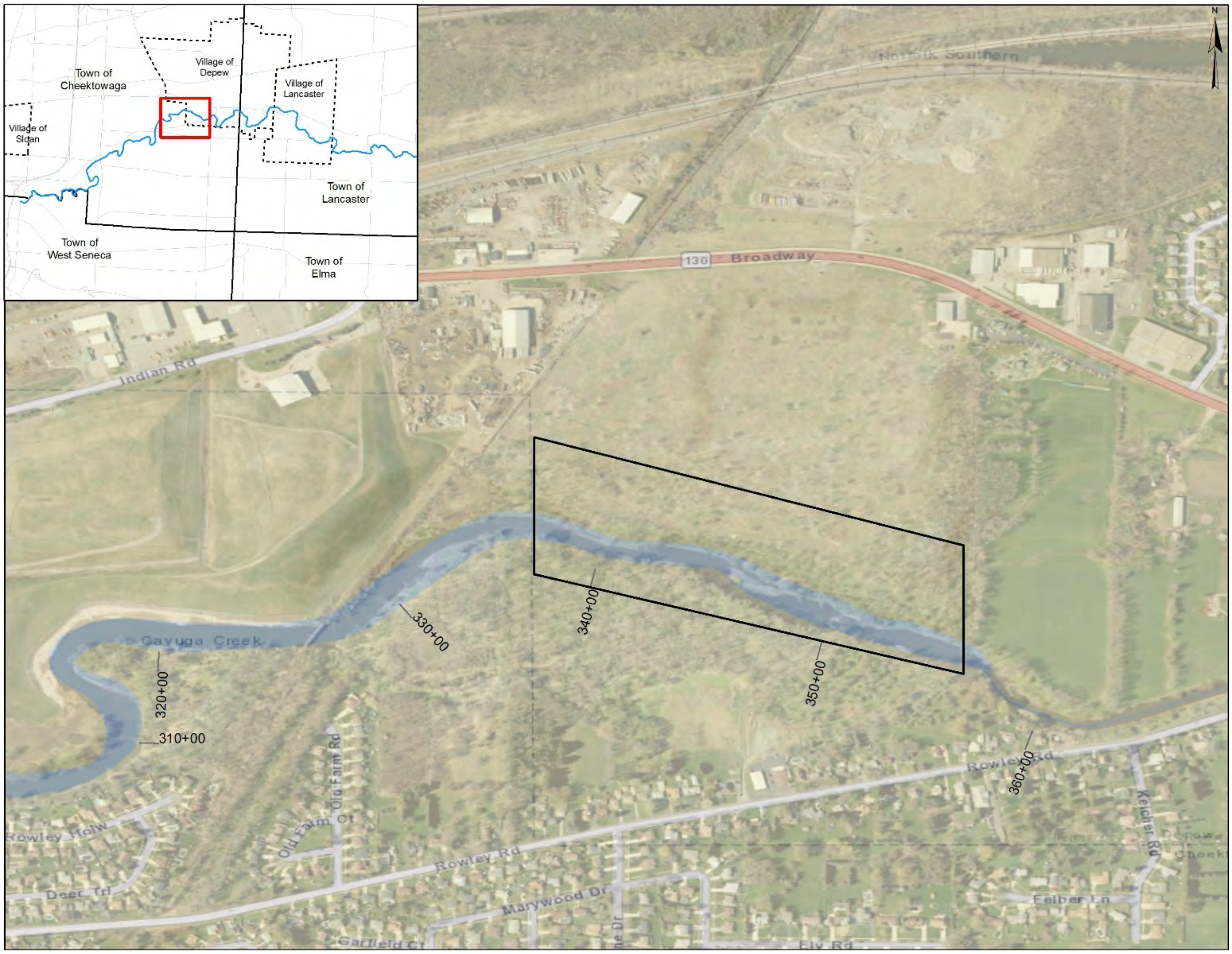

Figure 28. Alternative #1-5 location map.

In addition, this reach is in close proximity to the Village of Depew Old DPW Landfill and Twin Village Recycling yard. Waste from these facilities have been found along the banks and within Cayuga Creek, leading to pollution and adverse effects on creek and bank ecosystems (Figure 29).

Figure 29. Stream bank degradation and pollution in the vicinity of the Old DPW landfill along Cayuga Creek in the Village of Depew, NY.

Streambank protection consists of restoring and protecting banks of streams against scour and erosion. These systems can be used alone or in combination. The two basic categories of protection measures are those that work by reducing the force of water against a streambank and those that increase their resistance to erosive forces. These measures can be combined into a system. Streambank protection systems include (NRCS 2002):

Vegetative Plantings:

Use of conventional plantings of vegetation to protect streambanks.

Soil Bioengineering Systems

A system of living plant materials, such as shrubs and trees, used as structural components installed in specified configurations that offer immediate soil protection and reinforcement. Examples include:

- Live Stakes
- Live Fascines
- Vegetated Geogrids
- Live Cribwall/Lunker

- Brushmattress
- Live Sillation
- Branchpacking
- Reed Clumps
- Coconut Fiber Rolls

Structural Systems

Constructed systems, such as tree revetments, log, root wad, and boulder revetments, dormant post plantings, rock riprap, stream barbs and gabions, that offer soil protection and reinforcement. Examples include:

- Rock Riffle
- Tree Revetment
- Log, Root wad, Boulder Revetment
- Dormant Post Planting
- Rock Riprap
- Rock Gabions
- Stream Barbs/Bendway Weir

There are a variety of remedies available to minimize the susceptibility of streambanks to disturbance-caused erosive processes. They range from vegetation-oriented remedies, such as soil bioengineering, to engineered grade-stabilization structures. In the recent past, many organizations involved in water resource management have given preference to engineered structures. Structures may still be viable options; however, in a growing effort to restore sustainability and ensure diversity, preference should be given to those methods that restore the ecological functions and values of stream systems. As a first priority consider those measures that (NRCS 2002):

- Are self-sustaining or reduce requirements for future human support
- Use native, living materials for restoration
- Restore the physical, biological, and chemical functions and values of streams or shorelines
- Improve water quality through reduction of temperature and chronic sedimentation problems
- Provide opportunities to connect fragmented riparian areas
- Retain or enhance the stream corridor or shoreline system

In order to determine the appropriate streambank protection measure, a site assessment should be performed to determine if the causes of instability are local (e.g., poor soils, high water table in banks, alignment, obstructions deflecting flows into bank, etc.) or systemic in nature (e.g., aggradation due to increased sediment from the watershed, increased runoff due to urban development in the watershed, degradation due to channel modifications, etc.). The assessment need only provide the detail necessary for design of the bank treatments and reasonable confidence that the treatments will perform adequately for the design life of the measure (NRCS 2020).

After deciding rehabilitation is needed, the planning and selecting of one or multiple streambank protection measures should take into consideration the site assessment findings and a range of hydrologic and hydraulic data, which includes watershed, soils, and environmental data, stream reach characteristics and classifications, climatic and vegetative conditions, habitat characteristics, and local socio-economic factors (NRCS 2002).

Once streambank protection measures have been chosen, design and specification plans and operational and maintenance plans need to be developed. Design and specification plans describe the requirements for applying the protection measure according to Natural Resources Conservation Service (NRCS) Code 580 and applicable state and local standards. Provisions to minimize erosion and sediment production during construction, and provisions necessary to comply with conditions of any environmental agreements, biological opinions, or other terms of applicable permits should be included. At a minimum, a design and specifications plan should include (NRCS 2020):

- A plan view of the layout of the streambank and shoreline protection
- Typical profiles and cross sections of the streambank and shoreline protection
- Structural drawings adequate to describe the construction requirements
- Requirements for vegetative establishment and mulching, as needed
- Safety features
- Site-specific construction and material requirements

Operational and maintenance plans, at a minimum, should include (NRCS 2020):

- Instructions for operating and maintaining the system to ensure that it functions properly
- Periodic inspections and prompt repair or replacement of damaged components or erosion
- Instructions for maintaining healthy vegetation, when required
- Instructions for controlling undesirable vegetation

No cost estimates were prepared for this alternative due to the variable and case-by-case nature of streambank protection measures. Local municipal leaders, in conjunction with state agencies and environmental engineering firms, should determine if streambank protection measures are a viable flood mitigation strategy for their given area and then follow the outlined process in order to select, design, and construct the chosen measure.

HIGH RISK AREA #2

Alternative #2-1: Increase the Borden Road Bridge Opening

This measure is intended to address issues within High Risk Area #2 by increasing the height and width of the Borden Road bridge opening, which would increase the cross-sectional flow area of the channel located at river station 374+08. This bridge, owned by Erie County, NY, is a double arch bridge with a single central pier in the middle of the channel. The topography in the vicinity of the bridge is comprised of steep vertical overbanks constricting water flow into the narrow channel. Immediately upstream of the bridge is a sharp near 180º meander in the creek path. According to the FEMA FIS and HEC-RAS base condition model, the Borden Road bridge is undersized causing backwater at annual-chance flood levels greater than or equal to 10%, and does not allow the required 2-feet of freeboard over the 1% annual-chance flood water surface elevation. The constriction of flow in the channel increases the potential for ice-jam formation and backwater flooding upstream of the bridge (Figure 30).

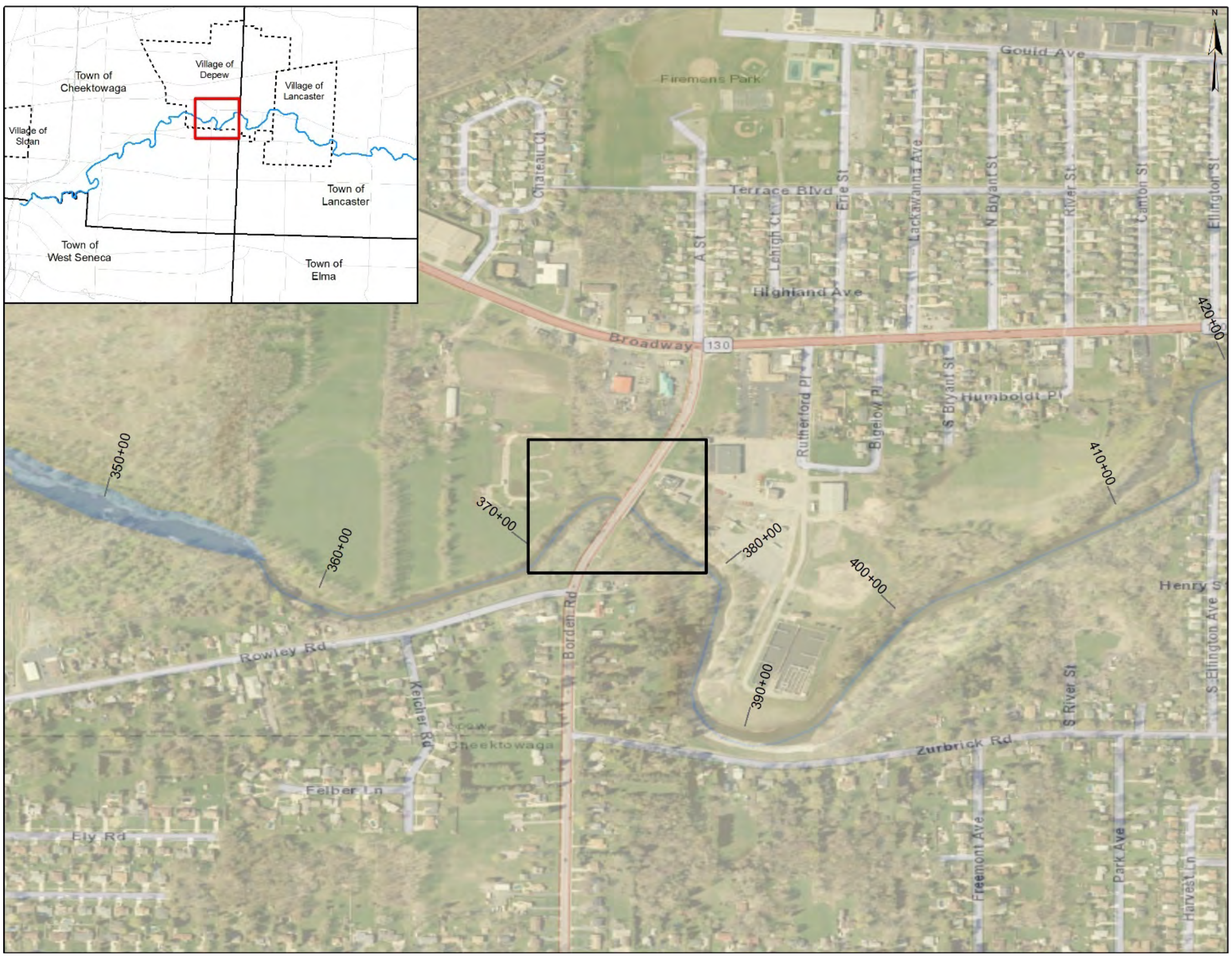

Figure 30. Alternative #2-1 location map.

The proposed condition modeling confirmed that the Borden Road bridge and the surrounding topography is a constriction point along Cayuga Creek. Three different bridge widening scenarios were modeled to assess the effectiveness of increasing the bridge opening on water surface elevations. The widening scenarios increased the cross-sectional flow area of the bridge on both sides of the central pier by approximately 10%, 100%, and 110% of the current flow area. The cross-sectional flow area was increased by increasing the vertical height of the low chord elevation and/or horizontal width of the bridge opening. Table 8 is a summary of the model simulation results for water surface elevation change by percent increase in cross-sectional area at the 1% annual-chance flood event.

Proposed Bridge Re-design (ft)	Cross-Sectional Area Increase	Water Surface Elevation Reduction (ft)
Raise low chord elevation 2-ft	10%	1.2
Raise low chord elevation 2-ft and increase span by 50-ft	100%	1.9
Raise low chord elevation 4-ft and increase span by 50-ft	110%	2.0

The proposed condition modeling simulation results indicated water surface reductions of up to two feet immediately upstream of the Borden Road bridge (Figure 31). The modeling output for future conditions displayed similar results with water surface elevations up to 0.5-ft higher due to the increased discharges associated with predicted future flows in Cayuga Creek.

To assess the influence of ice jams on the Borden Road bridge, an ice cover simulation with 1-foot ice thickness was performed. This simulation was intended to mimic the effects of an ice jam upstream of the ridge, which would reduce cross-sectional area and increase the in-channel roughness. When compared to existing conditions with ice cover, the simulation results indicated that for a 10-year flood event with approximately 9,510 cfs and a 1-foot thick ice cover, water surface elevations would be unaffected for the 10% bridge opening, and reduced up to 0.25-ft for the 100% and 110% bridge opening (Figure 32).

The Borden Road bridge is a double arch opening bridge with a large center pier in the middle of the channel. The topography of Cayuga Creek upstream of the bridge is sinuous and narrow. When ice cover forms in the creek upstream and an ice break-up event occurs, ice pieces can get caught on the outside banks of the meanders in the creek as they approach the Borden Road bridge, the center pier of the bridge, and along the abutments of the bridge. All of these factors act to restrict water flow in the channel, increasing the potential for ice-jam formation and backwater flooding. Widening the bridge arches either vertically and/or horizontally can increase the cross-sectional area of the creek channel in the vicinity of the bridge, allowing more ice pieces and water to flow downstream and potentially reducing the risk of ice-jam formations and flooding.

The Rough Order Magnitude cost for this measure is $5 Million, not including land acquisition costs for survey, appraisal, and engineering coordination.

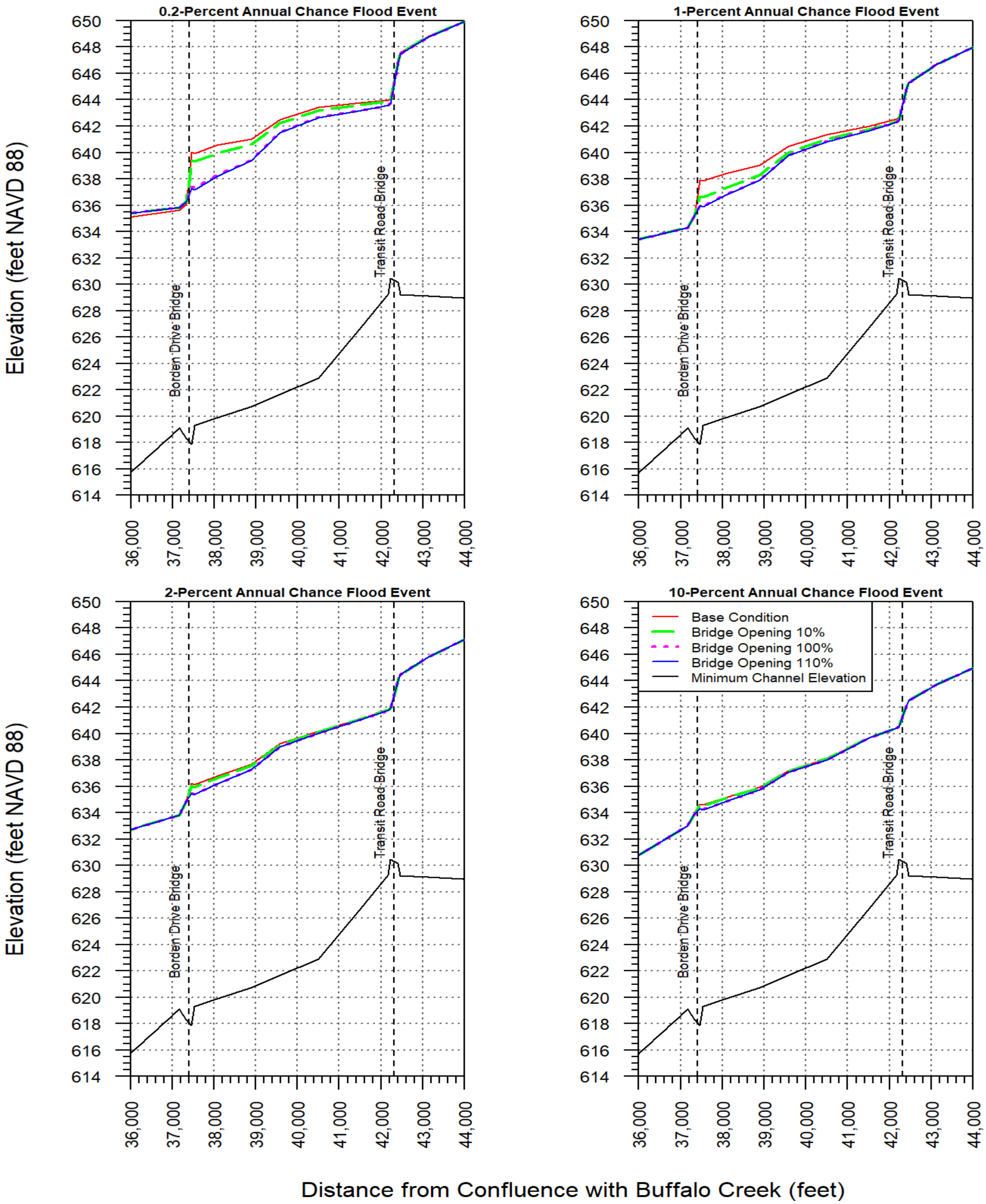

Figure 31. HEC-RAS proposed condition model simulation results for alternative #2-1.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the 10% (green), 100%l (magenta), and 110% (blue) increased cross-sectional flow area for the Borden Road bridge and base condition (red) model simulation results.

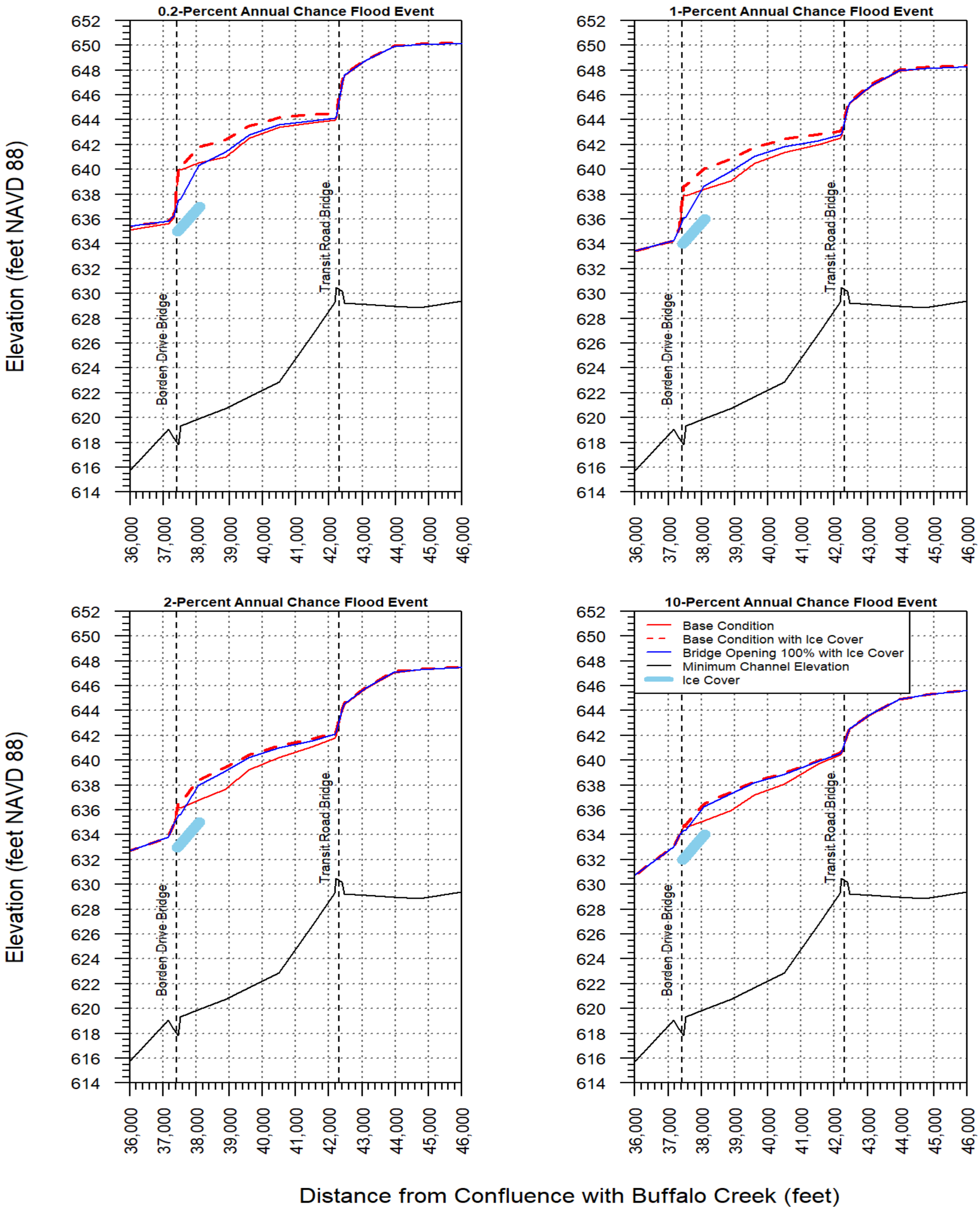

Figure 32. HEC-RAS ice cover model simulation results for alternative #2-1.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the 100% increased bridge opening with ice cover (blue), base condition with ice cover (red dashed), and base condition (red) model simulation results.

Alternative #2-2: Install Flood Bench Downstream of Penora Street Bridge

This strategy is intended to address issues within High Risk Area #2 by constructing a flood bench along the right bank of Cayuga Creek downstream of the Penora Street bridge in the Village of Depew, which would increase the cross-sectional flow and potential storage area. This reach is in the vicinity of the Broadway/US-20 bridge and a large commercial shopping center, including the D&L Plaza (Figure 33). This strategy would require the excavation of approximately 10.2 acres of land along the right bank of Cayuga Creek in order to construct a flood bench in this reach located downstream of the Penora Street bridge between river stations 435+00 and 458+00. 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.

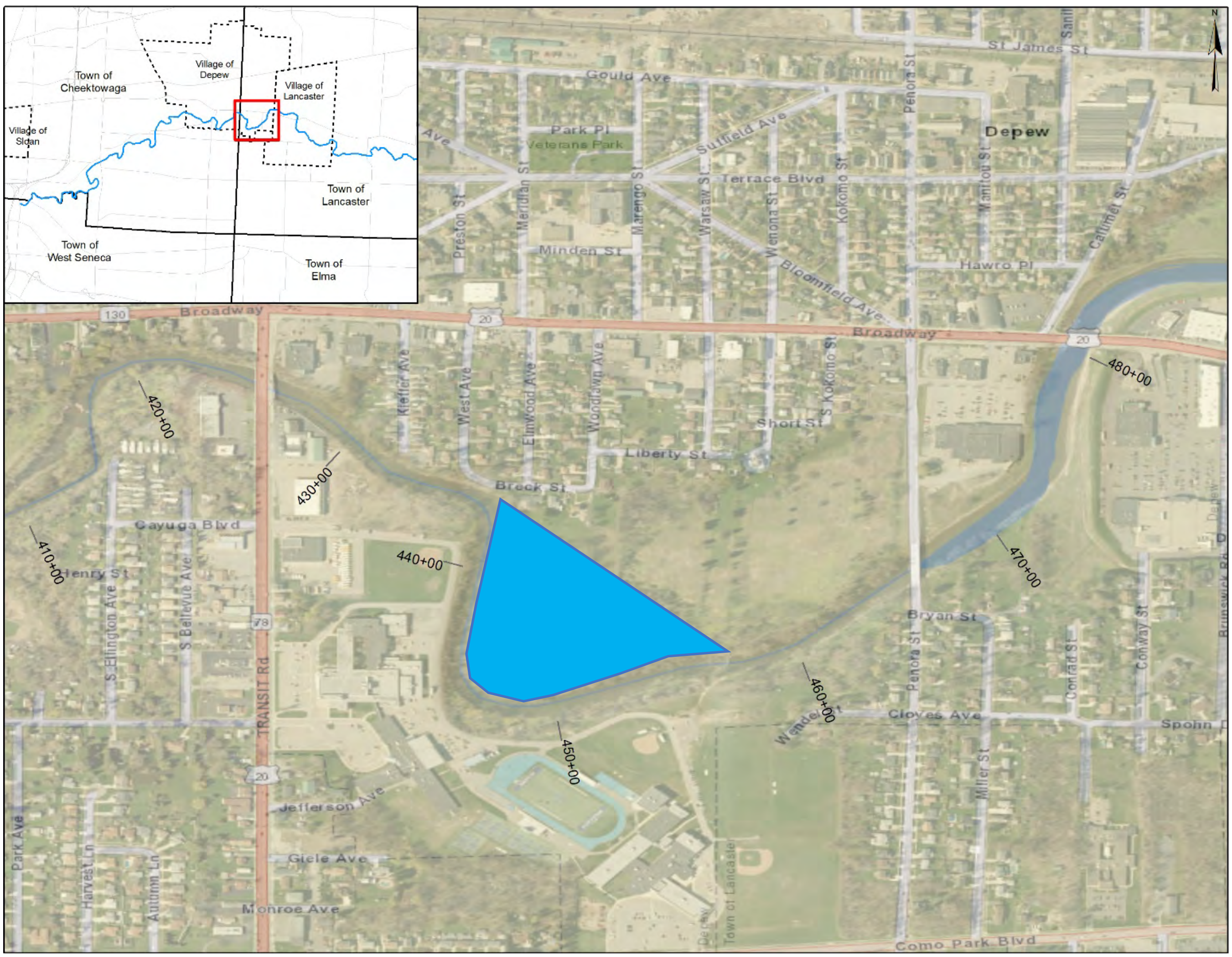

Figure 33. Alternative #2-2 location map.

In response to historical flooding in this area, a levee was built by the USACE in 1949 along the left bank of Cayuga Creek from upstream of the Aurora Street bridge, down to the southern edge of the D&L Plaza shopping complex just upstream of the Penora Street bridge. There is also a levee on the right bank that extends from the Lake Avenue bridge downstream to the northern edge of the D&L Plaza shopping complex. The levees upstream of the Penora Street bridge act to constrict high flows in the creek channel and accelerate the water velocity as it passes downstream under the bridge. There is a sharp 90º meander in the creek channel approximately 1,800-ft downstream of the Penora Street bridge. This meander causes water velocities to drop, leading to increases in water depths and potential flooding in the surrounding areas. In addition, most likely as a result of the levees constricting water flow, both the Penora Street and Broadway/US-20 bridges in the Village of Depew fail to provide the NYS CRRA recommended 2-feet of freeboard over the 1% annual-chance flood elevation according to the FEMA FIS.

The proposed condition modeling of a flood bench along the right bank of Cayuga Creek downstream of the Penora Street bridge indicated that potential flooding in this reach is more influenced by the channel path than geometry. Adding a flood bench provides additional storage area for low flow events, but the effectiveness of the flood bench diminishes with increasing flows. Based on the proposed condition simulation results, a flood bench would reduce water surface elevations in this reach by up to 0.7-ft (Figure 34). The future condition model output displayed similar results with water surface elevations up to 0.9-ft higher due to the increased discharges associated with predicted future flows in Cayuga Creek.

To assess the influence of ice jams on the Penora Street bridge, an ice cover simulation with 1-ft ice thickness was performed. This simulation was intended to mimic the effects of an ice jam upstream of the bridge, which would reduce cross-sectional area and increase the in-channel roughness. When compared to existing conditions with ice cover, the simulation results indicated that for a 10-yr flood event with approximately 9,510 cfs and a 1-ft thick ice cover, water surface elevations would not be reduced (Figure 35).

The Penora Street bridge has one central pier and an embankment on the left bank that narrows the creek channel. As a result, when surface ice forms in the upstream of the creek and reaches the bridge, the piers and the concrete embankment act as a barrier to, and restricts flow in the channel, increasing the potential for ice jam formation and incidental flooding. Further downstream, the 90° meander also has the potential to develop an ice jam from incoming upstream ice floes. If enough surface ice floes collect along the outer (left) bank of the meander, then an ice jam could form, which would restrict water flow in the channel and potentially cause flooding due to back water effects. A flood bench in this reach was modeled to be more beneficial at low flows, which is generally how ice-jam flooding occurs. In addition, water surface elevation reductions decrease with increasing discharge, as evidenced by the decreasing reductions of the 2, 1, and 0.2% annual-chance flood elevations when compared to the 10%.

By installing a flood bench, potential ice-jam flooding damages could be reduced in this reach allowing flow to enter the low-elevation flood bench rather than creating a stagnation location due to the 90° meander. The potential water surface elevation reduction benefits of this alternative would be in the immediate vicinity of the flood bench, specifically along river stations 440+00 to 465+00.

The Rough Order Magnitude cost for this measure is $4.4 Million, not including land acquisition costs for survey, appraisal, and engineering coordination.

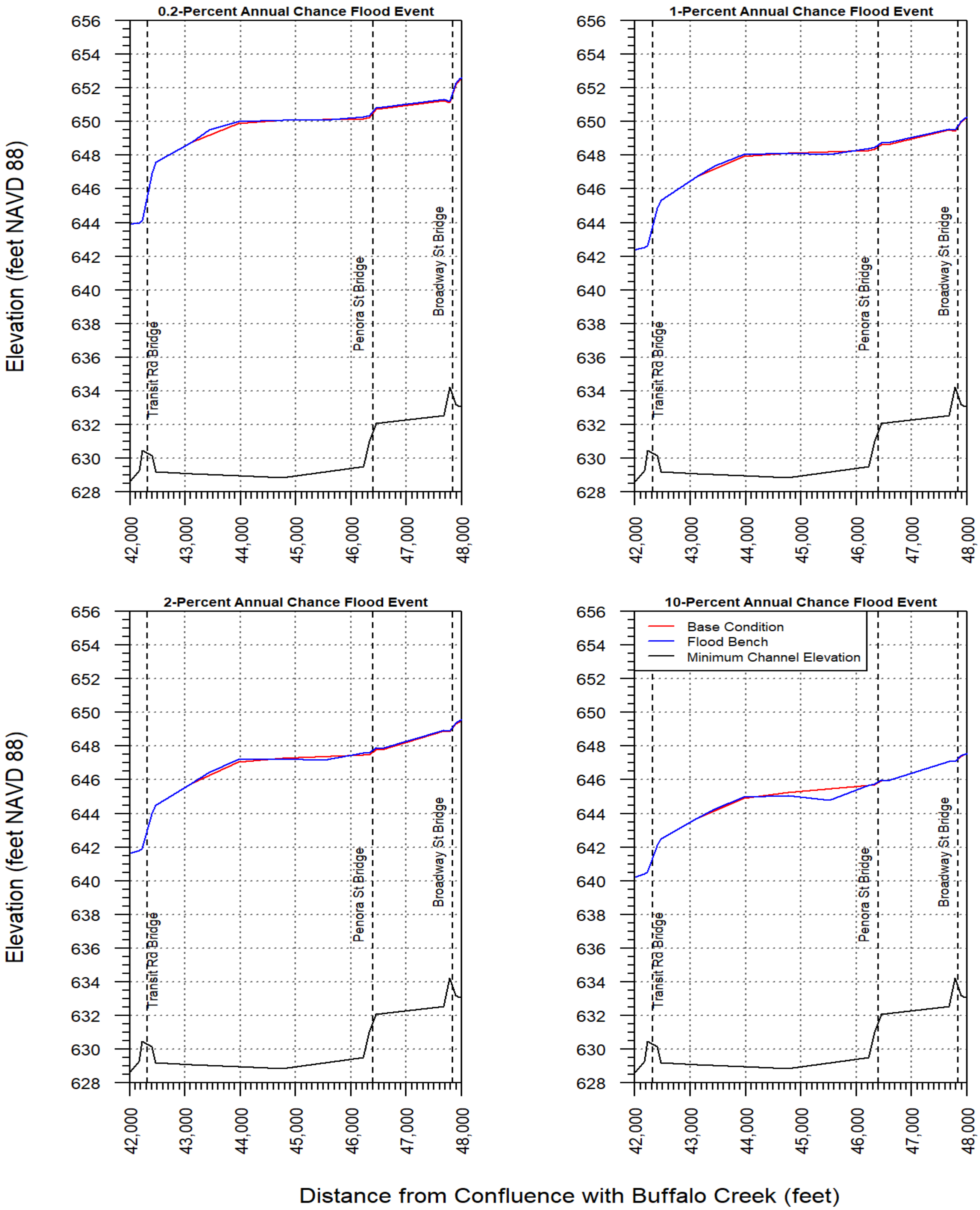

Figure 34. HEC-RAS proposed condition model simulation results for alternative #2-2.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the foot flood bench (blue) and base condition (red) model simulation results.

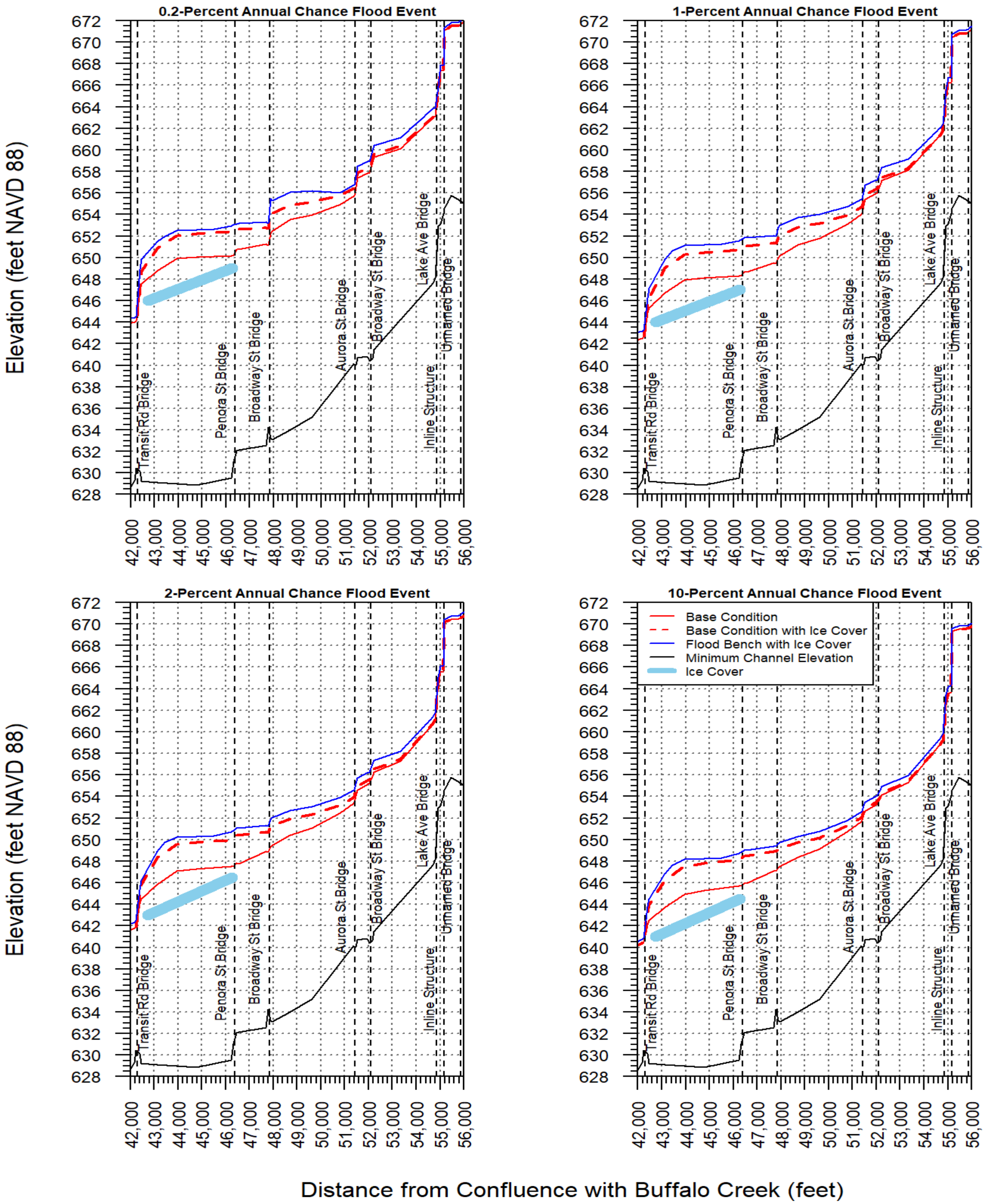

Figure 35. HEC-RAS ice cover model simulation results for alternative #2-2.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the flood bench with ice cover (blue), base condition with ice cover (red dashed), and base condition (red) model simulation results.

Alternative #2-3: Ice Control Structure – Penora Street Bridge

This strategy would need to be employed in conjunction with a flood bench project in order to provide the necessary storage area for ice collection and backwater caused by ice jamming. Ice control structures are constructed within the stream channel at a sufficient height where ice is captured within the channel. Water is then able to flow around the structures and captured ice (Lever et al. 2000). The structures direct the ice towards the flood bench which provides the required area to accommodate increased river stage during an ice-jam event. The flood bench would be located in the vicinity of the high-risk area downstream of the Penora Street Bridge between river stations 435+00 and 458+00. Figure 36 depicts the most optimal location for an ice control structure and flood bench downstream of the Penora Street bridge.

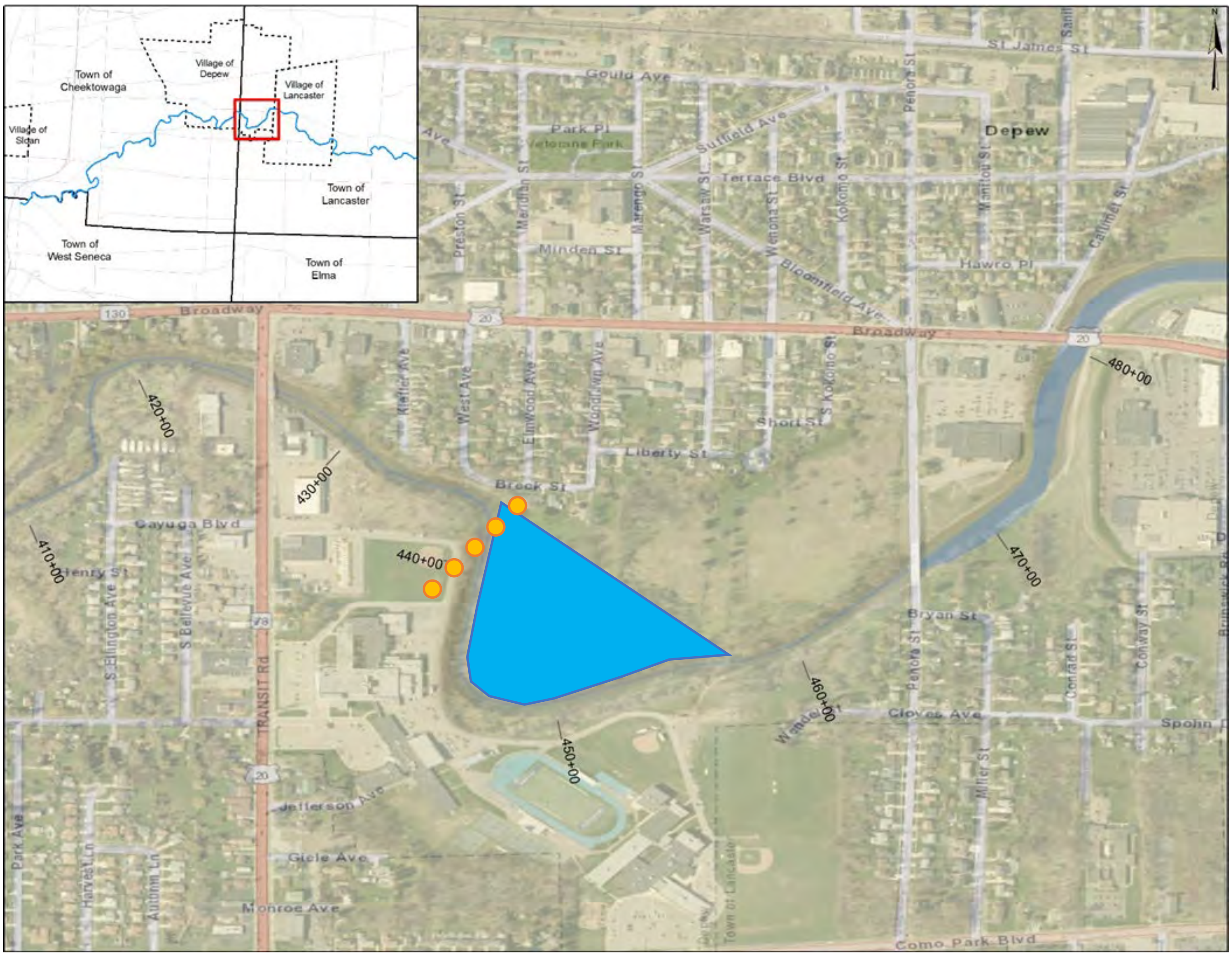

Figure 36. Alternative #2-3 location map.

Due to the complexity of freeze-up ice-jam modeling and the limited scope of this study, hydraulic modeling was not performed to assess the impact of this strategy. The frazil ice and surface ice formation, and their dynamics with the hydraulics are complicated due to the number of variables that are needed to model these scenarios (variables such as water depths, surface area, air temperature, water temperature, turbulent condition and flow velocity, etc.). Therefore, any suggested ice control structures or ice control structures with flood benches in Cayuga Creek, would need to go through a dynamic ice freeze-up and break-up computer modeling (2D River Ice Dynamic Simulation) simulation to understand the ice transport and ice generation mechanism with, and without the structures to support the proposed design. Poorly designed structures may result in worsening the flooding potential, and unexpected scour can impact the existing banks and infrastructure, instead of mitigating the ice-jam related flooding.

The Rough Order Magnitude cost for an ice control structure downstream of the Penora Street bridge would be approximately $9.6 Million, which includes construction of the flood bench, but does not include land acquisition costs for survey, appraisal, and engineering coordination.

HIGH RISK AREA #3

Alternative #3-1: Remove Sediment Under the Bowen Road Bridge Pier

This measure is intended to address issues within High Risk Area #3 by removing sediment underneath the pier and in areas upstream of the Bowen Road bridge, which would increase the cross-sectional area of the creek channel. The bridge, owned by Erie County, NY, is located at river station 645+61 and has one narrow pier, which sits approximately four-feet higher on the upstream side when compared to the downstream (Figure 37). By removing this four feet of sediment, the creek channel depth will increase and allow a greater volume of water to flow downstream under the bridge. This strategy would require the excavation of sediment from underneath the bridge pier and immediately upstream of the bridge (Figure 38).

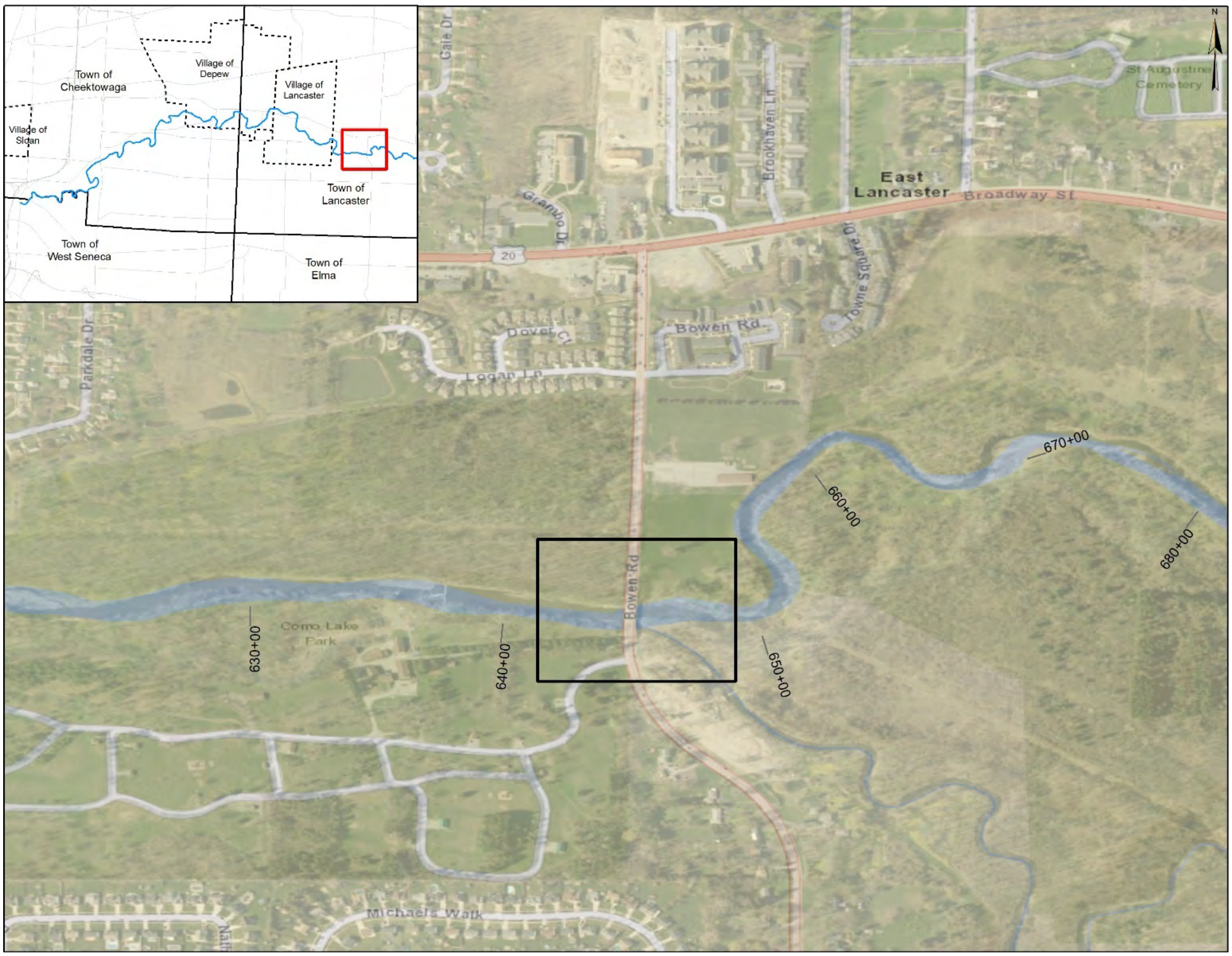

Figure 37. Alternative #3-1 location map.

Figure 38. Depositional sediment underneath and in the vicinity of the Bowen Road Bridge at river station 645+61.

Image Source: Friends of Reinstein Woods, 2016.

The proposed condition modeling confirmed that removing the sediment from underneath the central pier of the Bowen Road bridge would reduce water surface elevations. The simulation results indicated water surface reductions of up to 1-foot immediately upstream of the Borden Road bridge. The modeling output for future conditions displayed similar results with water surface elevations up to 0.6-ft higher due to the increased discharges associated with predicted future flows (Figure 39).

To assess the influence of ice jams on the Bowen Road bridge, an ice cover simulation with 1-ft ice cover thickness was performed. This simulation was intended to mimic the effects of an ice jam upstream of the bridge, which would reduce cross-sectional area and increase the in-channel roughness. When compared to existing conditions with ice cover, the simulation results indicated that for a 10-year flood event with approximately 9,510 cfs and a 1-ft thick ice cover, water surface elevations would be reduced up to 0.7-ft (Figure 40).

The sediment and sand bars that surround the Bowen Road bridge and its pier reduce the cross-sectional area of the channel. By removing the four feet of sediment under and around the Bowen Road bridge, water surface elevations were reduced in this reach according to the model simulations. The pier and sand bars also act to obstruct flow in the channel. This is important from an ice jam perspective since the piers and sand bars can catch ice floes potentially creating an ice jam, causing backwater flooding in the vicinity of the bridge. The potential water surface elevation reduction benefits of this alternative would extend both upstream and downstream of the Bowen Street bridge, specifically along river stations 640+00 to 690+00.

The Rough Order Magnitude cost for this measure is $100,000. The sediment underneath the pier and immediately upstream of the bridge is assumed to be depositional for this cost estimate. Further geologic analysis should be conducted in order to determine if there is any bedrock in the area. If there is determined to be bedrock then due to the technical, environmental, and cost complexity associated with bedrock removal, it is recommended that this mitigation recommendation not be pursued.

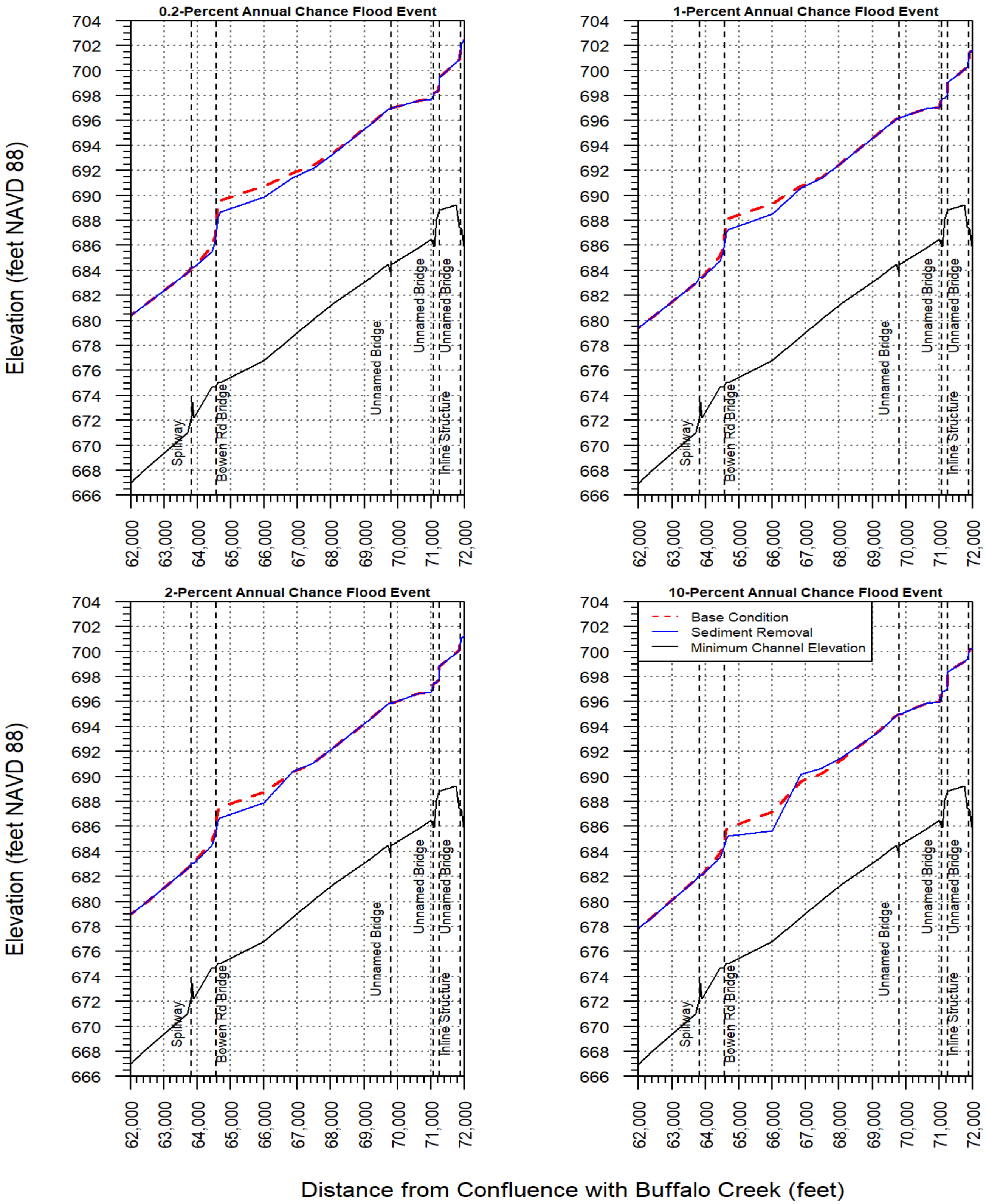

Figure 39. HEC-RAS proposed condition model simulation results for alternative #3-1.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the Bowen Road bridge sediment removal (blue) and base condition (red) model simulation results.

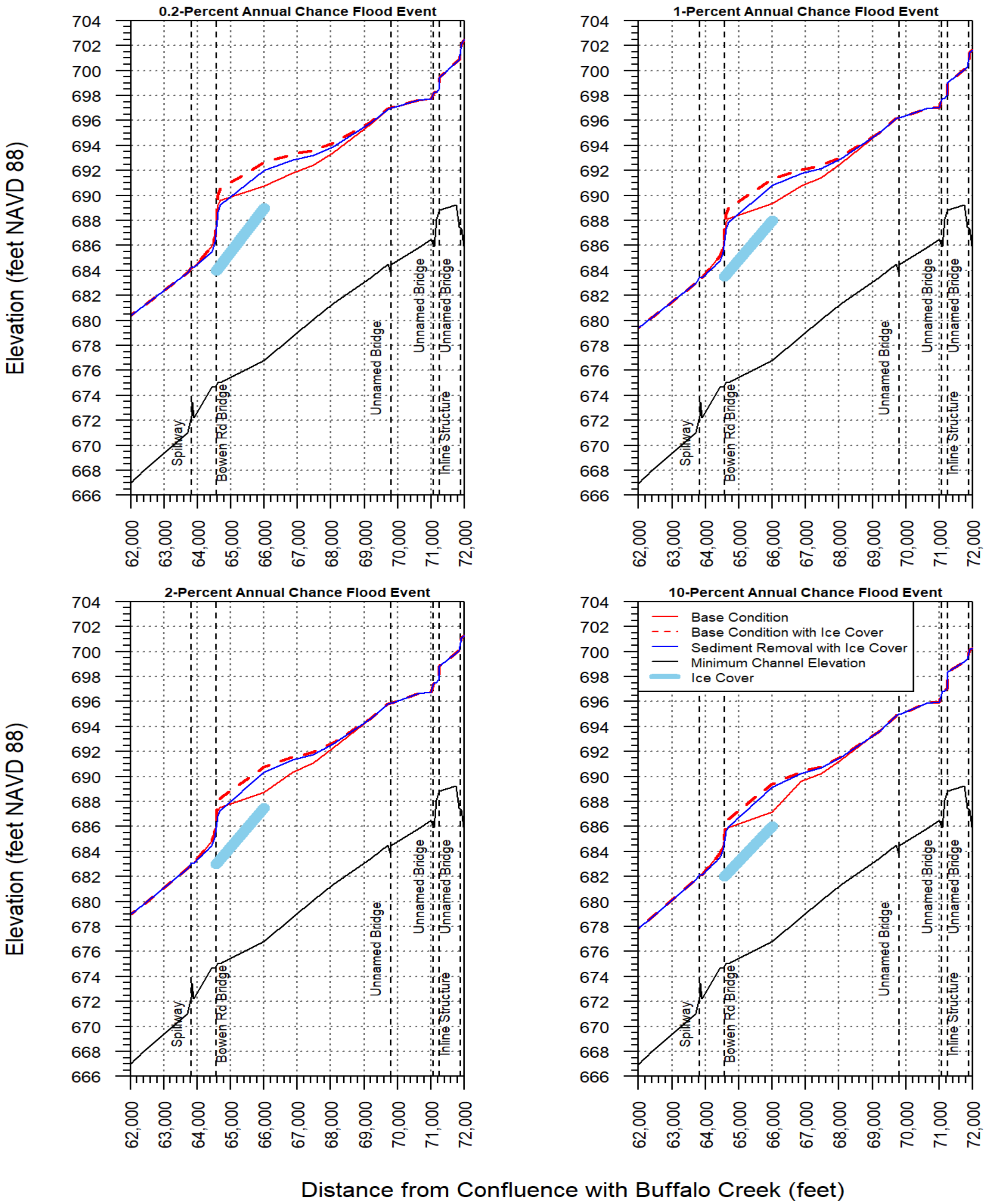

Figure 40. HEC-RAS ice cover model simulation results for alternative #3-1.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the Bowen Road bridge sediment removal with ice cover (blue), base condition with ice cover (red dashed), and base condition (red) model simulation results.

Alternative #3-2: Install Flood Bench Upstream of the Bowen Road Bridge

This strategy is intended to address issues within High Risk Area #3 by constructing a flood bench at the confluence of Little Buffalo Creek and Cayuga Creek upstream of the Bowen Road bridge in the Town of Lancaster, NY (Figure 41). This strategy would require the excavation of approximately 4.0 acres of land in order to construct a flood bench in this reach located between river stations 645+00 and 655+00. 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.

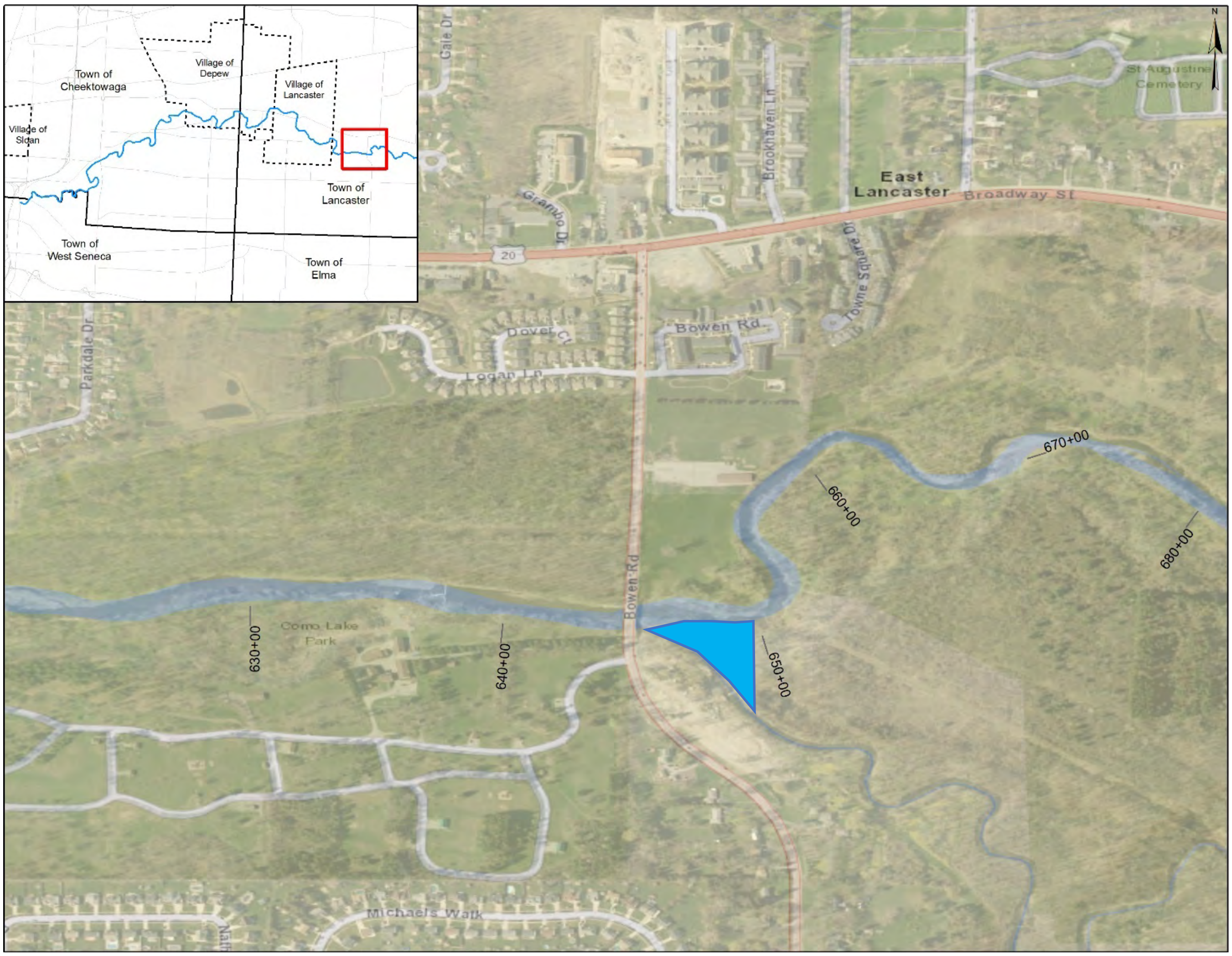

Figure 41. Alternative #3-2 location map.

The proposed condition modeling of a flood bench at the confluence of Cayuga and Little Buffalo Creeks indicated that potential flooding in this reach is influenced by proximity of the Bowen Road bridge. According to the model simulation output, any water surface reduction benefits of a flood bench in this reach are lost as flow passes through the Bowen Road bridge. Based on the proposed condition simulation results, a flood bench would reduce water surface elevations in this reach by up to 0.6-ft (Figure 42). The future condition model output displayed similar results with water surface elevations up to 1.0-ft higher due to the increased discharges associated with predicted future flows in Cayuga Creek.

To assess the influence of ice jams that a flood bench would have at the Bowen Road bridge, an ice cover simulation with 1-ft ice thickness was performed. This simulation was intended to mimic the effects of an ice jam upstream of the bridge, which would reduce cross-sectional area and increase the in-channel roughness. When compared to existing conditions with ice cover, the simulation results indicated that for a 10-yr flood event with approximately 9,510 cfs and a 1-ft thick ice cover, water surface elevations would be reduced up to 0.5-ft (Figure 43).

The Bowen Road bridge has one central pier and is immediately downstream of the confluence of Cayuga and Little Buffalo Creeks. There is a large deposit of sediment and bedrock in the vicinity of the bridge, in addition to the surrounding land features. As a result, when surface ice forms in the upstream of either Little Buffalo or Cayuga Creeks and reaches the bridge, the piers, embankment, and sediment/bedrock act as a barrier to, and restrict flow in the channel, increasing the potential for ice-jam formation and incidental flooding. If enough surface ice floes collect, then an ice jam could form, which would restrict water flow in the channel and potentially cause flooding due to back water effects. A flood bench in this reach was modeled to be more beneficial with increasing flows, which would potentially reduce flood damages from ice-jam events that cause high-flow water surface elevations.

By installing a flood bench, potential ice-jam flooding damages could be reduced in this reach allowing flow to enter the low elevation flood bench rather than creating a stagnation location due to the confluence of two creeks and the Bowen Road bridge. The potential water surface elevation reduction benefits of this alternative would be in the immediate vicinity of the flood bench, specifically along river stations 648+00 to 696+00.

The Rough Order Magnitude cost for this measure is $1.8 Million, not including land acquisition costs for survey, appraisal, and engineering coordination.

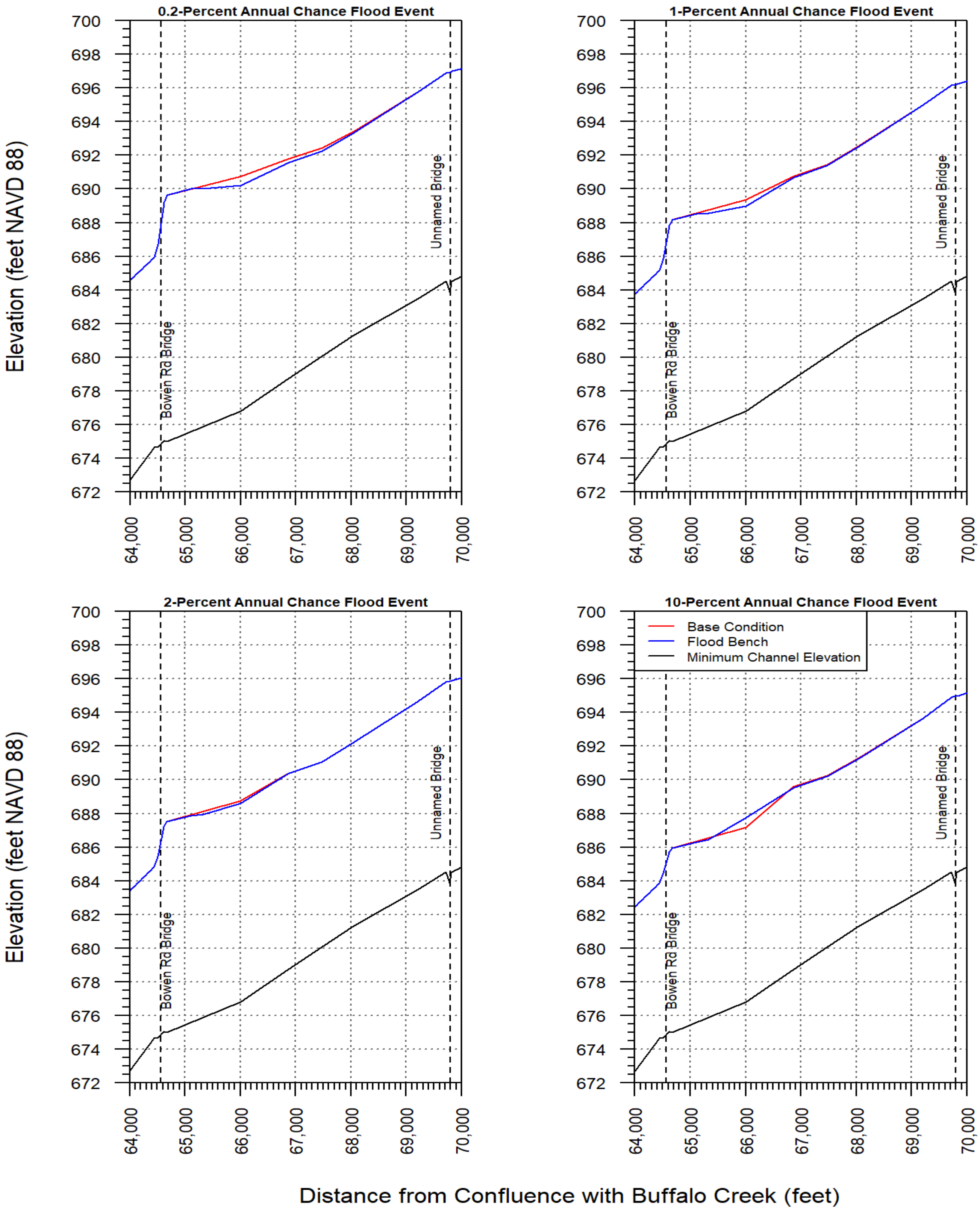

Figure 42. HEC-RAS proposed condition model simulation results for alternative #3-2.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the flood bench (blue) and base condition (red) model simulation results.

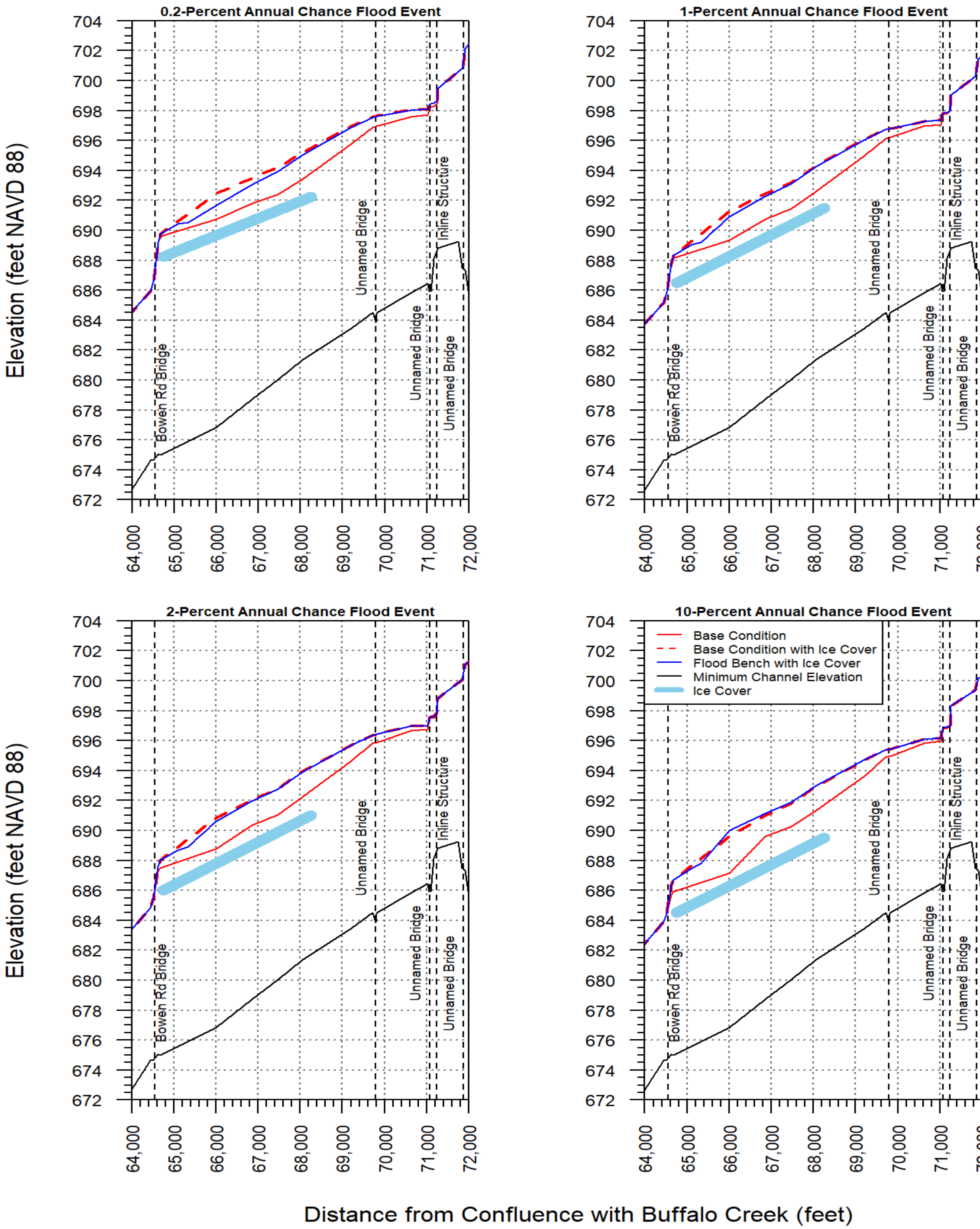

Figure 43. HEC-RAS ice cover model simulation results for alternative #3-2.

Note: The 10, 2, 1, and 0.2% annual-chance flood event water surface elevations (ft) for the flood bench with ice cover (blue), base condition with ice cover (red dashed), and base condition (red) model simulation results.

BASIN WIDE MITIGATION ALTERNATIVES

Early Warning Flood Detection System

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 2016a).

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 flood warning system consists of commercially available off-the-shelf-components. The major components of an early flood warning 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 2016a).

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 2016a).

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

Ice Management

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

Possible ice management strategies would include:

- Ice cutting – cut ice free from banks or cross-cut ice to hasten the release of ice in order to prevent ice-jam formations
- Trenchers and special design trenching equipment – used to dig ditches customarily, but can be used to cut ice to hasten release downstream
- Channeling plow – plow mounted to a sledge drawn by a tractor that breaks and clears ice from channel
- Water jet and thermal cutting – supersonic water streams and thermal cutting tools to separate ice and move it downstream
- Hole cutting – drill large holes into the ice to reduce the integrity of the ice cover and curtail ice formation
- Ice breakers – ships, hovercrafts, amphibious hydraulic excavators, construction equipment, and blasting techniques designed to break up 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 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-dimensional (2D) 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 annually (estimated six days for labor and basic equipment, not including costs associated with the procurement, operation, or maintenance of specialized equipment discussed above).

Flood Buyouts/Property Acquisition

Buyouts and acquisitions allow state and municipal agencies the ability to purchase developed properties within areas vulnerable to flooding from willing owners. Buyouts and acquisitions are effective management tools in response to natural disasters to reduce or eliminate future losses of vulnerable or repetitive loss properties. The terms buyout and acquisition are often used interchangeably, but they are distinct and serve distinct purposes (Siders 2013).

Acquisition is the general term and refers to the purchase of private property by government for public use. It is not confined to a particular purpose or end use for the property. Buyout programs, on the other hand, are a specific subset of acquisition in which private lands are purchased, existing structures demolished, and the land maintained in an undeveloped state for public use in perpetuity. Both buyout and acquisition programs can be conducted without the consent of the landowners by using eminent domain, but most often they are conducted with voluntary sales from landowners who have recently experienced a natural disaster (Siders 2013).

Acquisition programs can be designed for many purposes. Most often, following a disaster, they are intended to purchase damaged parcels from homeowners who are unwilling or unable to rebuild, thereby granting the homeowners the financial resources to relocate to a less vulnerable area. The parcels are then re-sold to a developer, who is held to stricter building requirements to make the new structure more resilient to natural threats. Acquisition programs designed in this way are intended to maintain similar amounts of housing and a similar local tax base in the affected community. Such programs may also improve the resilience of the community, by requiring developers to meet more stringent mitigation standards, but they will be no more resilient than communities where the original homeowners undertake mitigation programs. The main benefit is to the homeowner who is enabled to relocate (Siders 2013).

Buyout programs, on the other hand, are designed to permanently remove built structures and replace them with public space or natural buffers. Buyout programs not only assist individual homeowners but are also intended to improve the resiliency of the entire community in the following ways:

- 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. Acquisition programs do not produce the same results because the newly-built homes, even if built to be more resilient, are still vulnerable and may still suffer damage during subsequent events (Siders 2013).

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. Acquisition programs can be effective even if they purchase individual isolated homes, but buyout programs will be most effective when they purchase entire streets or neighborhoods (Siders 2013).

Acquisition and buyout programs can be funded entirely through state or local funds, but most often such programs occur after a nationally recognized disaster and use a combination of federal and state funds. The Federal Emergency Management Agency (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 an acquisition or 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).

Due to the variable nature of buyout or acquisition programs, no ROM cost estimate was produced for this study. It is recommended that any buyout or acquisition program begin with a cost-benefit analysis for each property. After a substantial benefit has been established, a buyout or acquisition strategy study should be performed that focuses on properties closest to Cayuga Creek in the highest-risk flood areas and progresses outwards from there to maximize flood damage 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

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 2015).

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).

In summary, the CFR does not allow for floodproofing of non-residential structures; however, there is one exception outlined in 44 CFR 60.6 (c) "a permit can be obtained to floodproof a residential building basement, if it can demonstrate an adequate warning time under a flood depth less than 5 feet and a velocity less than 5 fps." Instead, residential structures should be raised above the BFE in accordance with local regulations. Floodproofing is allowed for non-residential structures, with design guidelines outlined in FEMA P-936 – Floodproofing Non-Residential Structures (FEMA 2000; FEMA 2013). The local floodplain administrator should carefully review local ordinances, the CFR and available design guidelines perform issuing a permit for structural flood proofing. Floodproofing strategies include:

Interior Modification/Retrofit Measures

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

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 2015).

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% annual-chance (100-year) flood protection, a building must be dry floodproofed to an elevation at least 1-foot above the BFE (FEMA 2013).

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 2015).

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 2015). 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).

- <u>Floodwall with Gates and Floodwall without Gates</u>: 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 2015):

- 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.

NEXT STEPS

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

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-Dimensional (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.

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.

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 2D 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 indicate 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.

EXAMPLE FUNDING SOURCES

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

- New York State Office of Emergency Management (NYSOEM)
- Regional Economic Development Councils/Consolidated Funding Applications (CFA)
- National Resources Conservation Services Emergency Watershed Protection (EWP) Program
- U.S. Federal Emergency Management Agency - Unified Hazard Mitigation Assistance (HMA) Program

New York State Office of Emergency Management (NYSOEM)

The New York State Office of Emergency Management, through the U.S. Department of Homeland Security (DHS), offers several funding opportunities under the Homeland Security Grant Program (HSGP). 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.

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.

<u>Water Quality Improvement Project (WQIP) Program</u>

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.

<u>Climate Smart Communities (CSC) Grant Program</u>

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.

NRCS Emergency Watershed Protection (EWP) Program

Through the Emergency Watershed Protection (EWP) Program, the U.S. Department of Agriculture's Natural Resources Conservation Service 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.

FEMA Unified Hazard Mitigation Assistance (HMA) Program

The Federal Emergency Management Agency's Unified Hazard Mitigation Assistance (HMA) Program, 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 Pre-Disaster Mitigation (PDM) Program and the Flood Mitigation Assistance (FMA) Program.

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.

<u>Pre-Disaster Mitigation (PDM) Program</u>

The Pre-Disaster Mitigation Grant Program provides resources to reduce overall risk to the population and structures from future hazard events, while also reducing reliance on federal funding from future disasters. Federal funding is available for up to 75% of eligible activity costs. The PDM project funding categories include Advance Assistance (up to $200,000 total of federal share funding), Resilient Infrastructure (up to $10 million total of federal share funding), and Projects (up to $4 million per project).

<u>Flood Mitigation Assistance (FMA) Program</u>

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

SUMMARY & CONCLUSION

SUMMARY

The Town of Lancaster and Village of Depew, NY have had a long history of flooding events along Cayuga Creek. Flooding in the Town and Village primarily occurs during the late winter and early spring months and is exacerbated by ice jams. In response to persistent flooding, the State of New York in conjunction with the Town of Lancaster, Village of Depew, and Erie County are studying, addressing, and recommending potential flood mitigation projects for Cayuga Creek as part of the Resilient NY Initiative.

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

Based on the flood mitigation analyses performed in this report, the mitigation measures that provided the greatest reductions in water surface elevations were the flood bench upstream of the Bowen Road bridge, removal of the Rowley Road bridge, and increasing the bridge opening of the Borden Road bridge. The most cost effective of these alternatives would be removing the Rowley Road bridge. There would be an overall greater effect in water surface elevations if multiple flood bench and bridge alternatives were employed along Cayuga Creek in different phases, rather than a single mitigation measure with respect to both open water and ice-jam flooding events.

Other cost-effective alternatives that should be considered, are removing the inactive railroad bridge, and removing the sediment from under the Bowen Road bridge pier. Removing the inactive railroad bridge was not simulated to reduce water surface elevations at significant levels for open water flooding, however, the potential simulated reductions in water surface elevations for low flow ice-jam events was significant. Removing the sediment and sand bars around and under the Bowen Road pier would be a simple and cost-effective measure to reduce water surface elevations in a high flood risk reach of Cayuga Creek.

Ice management to control ice buildup at critical points along Cayuga 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.

The ice control structures would address both flooding from high flows and potential ice-jam flooding along Cayuga Creek. An ice control structure and associated flood bench would provide the greatest protection from both types of flooding that occur on Cayuga Creek by combining the benefits of a flood bench, with the ice management of the ice control structures. However, a comprehensive ice analysis should be done to make sure that the ice control structures work well during both open water and wintertime, without adversely affecting the existing infrastructure.

Streambank protection involves utilizing measures or practices that stabilize and protect banks of streams in order to prevent the loss of land or damage to land uses or facilities adjacent to the banks of streams, maintain the flow capacity of channels, reduce the offsite or downstream effects of sediment resulting from bank erosion, and improve or enhance the stream corridor for fish and wildlife habitat, aesthetics, and recreation (NRCS 2020). Site assessments and hydrologic and hydraulic studies, including geotechnical evaluations, should be performed to inform decisionmakers regarding the best available protection measures to employ. There are numerous potential benefits of a well-crafted streambank protection plan, including pollutant protections, bank stabilization, reduction of erosion and sediment transport downstream, and improved water quality and aquatic habitats. Every creek and every reach within a creek is different, so streambank protection measures should be decided using a site-specific approach.

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 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 10 provides a summary of the flood mitigation alternatives, their modeled influence on water surface elevations, and associated ROM costs.

Table 10. Summary of Flood Mitigation Measures

Alternative No.	Description	Change in Water Surface Elevation (ft)	ROM cost ($U.S. dollars)
1-1	Widen/Remove the Rowley Road Bridge	Up to – 2.5 feet	$750,000 (Removal) $4.7 Million (Widen)
1-2	Remove Inactive Railroad Bridge	Up to – 0.8 feet	$210,000
1-3	Install Flood Bench in Vicinity of Inactive Railroad Bridge	Up to – 1.0 feet	$1.6 – 4.8 Million
1-4	Ice Control Structure with Flood Bench – Inactive Railroad Bridge	N/A	$7 Million
1-5	Stream Bank Stabilization – Village of Depew Old DPW Landfill	N/A	Varied (case-by-case)
2-1	Increase the Borden Road Bridge Opening	Up to – 2.0 feet	$5 Million
2-2	Install Flood Bench Downstream Penora Street Bridge	Up to – 0.7 feet	$4.4 Million
2-3	Ice Control Structure with Flood Bench – Penora Street Bridge	N/A	$9.6 Million
3-1	Remove Sediment Under Bowen Road Bridge Pier	Up to – 1.0 feet	$100,000
3-2	Install Flood Bench Upstream of Bowen Road Bridge	Up to – 0.6 feet	$1.8 Million
Basin Wide Mitigation Alternatives	Early Warning Flood Detection System	N/A	$120,000
	Ice Management	N/A	$40,000 (not including annual operational costs)
	Flood Buyouts/Property Acquisitions	N/A	Varied (case-by-case)
	Floodproofing	N/A	Varied (case-by-case)

CONCLUSION

Communities affected by flooding along Cayuga 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 Cayuga 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 steps below:

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 Cayuga Creek based on feasibility, permitting, effectiveness and available funding
5. Develop a preliminary engineering design report and cost estimate for the 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 flood mitigation strategy can begin.

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